THE EFFECT OF HAND DRYER FAN PARAMETER ON NOISE AND AERODYNAMIC LEVEL

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I hereby, declared this report entitled "The Effect of Hand Dryer Fan Parameter on Noise and Aerodynamic Level" is the result of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for the degree of Bachelor Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRAK

Matlamat penyelidikan ini adalah untuk menambah baik reka bentuk semasa pengering tangan dengan memanipulasi parameter input berbeza yang boleh dilaksanakan untuk mengoptimumkan tindak balas output. Parameter input ditakrifkan dari segi dua aspek iaitu jenis reka bentuk muncung dan jenis penebat. Manakala tindak balas keluaran yang akan dinilai termasuklah halaju udara (MPH), tahap kebisingan (dB) dan masa pengeringan dalam (s). Kaedah menjalankan penyelidikan ini adalah dengan melaksanakan reka bentuk Faktor Penuh dalam Reka Bentuk Eksperimen (DoE) di mana jumlah eksperimen adalah sebanyak 9 kali berdasarkan 2 faktor pada 3 tahap. Muncung krom, muncung penumpu dan muncung peresap mewakili jenis reka bentuk muncung manakala kadbod telur, baji dan buih akustik piramid mewakili jenis penebat. Keputusan menunjukkan bahawa kombinasi terbaik yang dicadangkan oleh perisian Design Expert adalah kombinasi muncung krom dengan buih baji dan buih piramid sebagai muncung yang dipasang di saluran keluar udara dan juga digunakan sebagai penebat dalam perumah motor dalaman pengering tangan, masing-masing. Ketiga-tiga gabungan parameter ini telah memberikan output yang paling diingini dan telah mencapai matlamat projek ini iaitu untuk mempunyai tahap kebisingan yang paling rendah, masa pengeringan yang paling singkat dan halaju udara yang paling tinggi. Tambahan pula, ini juga telah membuktikan bahawa kesan parameter kipas pengering tangan yang melibatkan gabungan muncung krom dengan buih baji dan buih piramid telah menghasilkan kesan yang paling besar terhadap pengurangan tahap kebisingan dan tahap aerodinamik pengering tangan.

ABSTRACT

The aim of this research is to improve the current design of the hand dryer by manipulating different input parameters that can be implemented to optimise the output responses. The input parameters are defined in terms of two aspects which are the type of nozzle design and the type of insulation. Whereas the output responses to be evaluated are the air velocity in (MPH), noise level in (dB) and drying time in (s). The method of conducting this research is by implementing the Full Factorial design in the Design of Experiment (DoE) with a total of 9 runs of experiments provided with 2 factors at 3 levels. The chrome nozzle, concentrator nozzle and diffuser nozzle represent the type of nozzle design whereas the egg carton, wedge and pyramid acoustic foam represent the type of insulation. The results revealed that the best combination suggested by the Design Expert software are the chrome nozzle with wedge foam and pyramid foam as the nozzle installed at the air outlet and also used as insulations in the internal motor housing of the hand dryer, respectively. All three of these parameters combination has given the most desirable output and have achieved the aim of this project which is to have the lowest noise level, shortest drying time and highest air velocity. Furthermore, this has also proven that the effect of hand dryer fan parameter which involved the combination of chrome nozzle with wedge foam and pyramid foam has produced the greatest impact on the reduction of noise level and aerodynamic level of the hand dryer.

DEDICATION

Only
my beloved father, Eric Cheak Yoong Peng
my appreciated mother, Tay Siok Eng
my adored sister and brother, Diana, Christina and Jason
for giving me moral support, money, cooperation, encouragement and also understandings
Thank You So Much & Love You All Forever

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LIST OF ABBREVIATIONS

3D	-	3-Dimensional
ADA	-	Americans with Disabilities Act
DoE	-	Design of Experiment
Et.al	-	Et alia
HEPA	-	High-Efficiency Particulate Absorbing
n.d.	-	No date
N/A	-	Not Applicable
NIOSH	-	National Institute for Occupational Safety and Health
NRC	-	Noise Reduction Coefficient
OSHA	-	Occupational Safety and Health Administration
PCB	-	Printed Circuit Board
PSM	-	Projek Sarjana Muda
PU	-	Polyurethane
SLM	-	Sound Level Meter
SPL	-	Sound Pressure Level
STC	-	Sound Transmission Class
Std.Dev.	-	Standard Deviation
VFD	-	Variable Frequency Drive
Vs.	-	Versus
WHO	-	World Health Organisation
Std.Dev	-	Standard Deviation
Obs	-	Observations
2FI	-	Two-Factor Interaction
ANOVA	-	Analysis of Variance
Prob > F	-	Probability of full model is true
DF	-	Degrees of Freedom
PRESS	-	Prediction Sums of Squares
C.V.	-	Coefficient of Variation
Adj R-Squared	-	Adjusted R-Squared

Pred R-Squared	-	Predicted R-Squared
Adeq Precision	-	Adequate Precision
CI	-	Confidence Interval
PI	-	Prediction Intervals
VIF	-	Variance Inflation Factors
LSD	-	Least Significant Difference
SE Mean	-	Standard Error of the Mean
SE Pred	-	Predicted Standard Error

LIST OF SYMBOLS

"	-	Inch
%	-	Percent
μPa	-	Micro Pascal
A	-	Ampere
CFM	-	Cubic Feet per Minute
dB	-	Decibels
dBA	-	A-weighted decibels
ft	-	Feet
h	-	Hour
Hz	-	Hertz
I	-	Current
k	-	Kilo
LFM	-	Linear Feet per Minute
m/s	-	Meter per second
MPH	-	Miles per hour
P	-	Power
rpm	-	Revolution per minute
s	-	Seconds
V	-	Voltage
V	-	Volts
W	-	Watt
+	-	Plus
-	-	Minus

CHAPTER 1
INTRODUCTION

1.0 Overview

The Chapter 1 Introduction basically comprises seven subtopics. The subtopics include the background of study, problem statement, objectives, scope, importance of study, organization of the thesis and lastly the summary. The details of each element will be discussed comprehensively in the following subtopics.

1.1 Background of Study

The effects of the noise levels for the high speed hand dryers have been investigated on the population. The most common concerns that have been raised among these studies are the loudness of the hand dryer itself and the high frequency content of the noise (Desvard et al., 2014). High level of noise can be considered as an unsettling influence that can impact indirectly to the human environment (Owoyemi et al., 2017). In industries, noise is always aimed to be reduced since it is an occupational hazard that can gives impacts on workers' wellbeing for a long run.

In terms of industrial operations, noise also presents the wellbeing and social issues whereby the source is most often related to the utilization of machines or appliances within the industries (Owoyemi et al., 2017). In general, noise can be found everywhere including the workplace especially in industries whereby most of the noise sources came from either the machines or the appliances. The sound pressure level (SPL) which is measured in decibels (dB) generated differs from one another depending on several aspects which include the type of the noise source, distance between the noise source and the receiver, and the working environment nature (Therrien & Tummala, 2020).

At the same time, noise can also cause stress, discomfort and even worst with some degree of disorder to an exposed individual which may potentially affect one's privacy and concentration in performing tasks within the affected working environment (Becker & Lavee, 2003). Additionally, those workers who works in heavy industries that involve particularly higher noise level are more prone to have health at risk (Bamane et al., 2019). Hence, it is very crucial to find out effective yet harmless methods for noise control in order to improve the workplace environment and reduce unwanted noise in industries (Bamane et al., 2019).

1.2 Problem Statement

Fundamentally, the general rule of thumb for a hand dryer states that the fastest the hand-dryer, the louder the sound will be (J. L. Drever, 2017). In other words, it also means that when the fan speed in (rpm) increases, the noise or the sound pressure level (SPL) which is measured in decibel (dB) will also increases. Since the fan speed is operating at a high speed, thus it operates efficiently with a shorter drying time but also produces a lot of noise at the same time (*Fan Speed, Bearings, and Noise*, n.d.). Thus, the general rule of thumb for the hand dryer is not fully applicable in this study since the noise level will not be reduced but instead it has high probability that the noise level might increase.

Apart from that, noise can also be a great concern when it comes to deal with applications such as the industrial ventilation as high acoustic levels tend to promote worker fatigue (IOSH, 2018). In some cases, parameters such as the airflow rate, type of fan, and pressure may also generate noise in fan motor. Often, inefficient fan operation will be indicated by a relatively high noise level for a specific type of fan. Still, an oversized fan or motor assembly creates an opposite set of operating problems which include excess airflow noise, inefficient fan operation, poor reliability, and duct or pipe vibrations (Lawrence Berkeley National Laboratory Washington, 2003).

Commonly, the type of fan found in the hand dryer motor is the axial fan which is typically moves airstream along the axis of the fan. The working principle of the axial fan is by pressurizing the air alongside with the aerodynamic lift generated by the fan blades which is similar to an airplane wing and propeller. In addition, an axial fan tends to be noisier since it has higher rotational speeds compared to an in-line centrifugal fans of the same capacity (Gustafson et al., 2003). Nonetheless, this noise can be controlled by high frequencies and reduced gradually (Lawrence Berkeley National Laboratory Washington, 2003).

1.3 Objectives

1) To investigate the existing default design of the hand dryer model.
2) To analyse the correlation between the input parameters and the response.
3) To suggest the best combinations of input parameters that gives the optimum response in order to obtain the best result.

1.4 Scope

The aim of this project is to improve the current design of the hand dryer. The scope of the project will be focusing based on the following:

1) To find the optimum fan speed at minimum noise level with acceptable drying time.
2) To propose optimum flow directing outlet design (shape and dimension) with respect to air flow rate.
3) To propose additional damping mechanism and noise insulator on the component.

In order to find the optimum fan speed at minimum noise level with acceptable drying time, the detail works comprises of the design and fabrication of test rig, experimental setup or the speed controller. The elements that can be used to reduce noise to the minimum level with optimum fan speed are including the speed controller, soundproof container, sound level meter, acrylic, insulator foam, anemometer, printed circuit board (PCB), and labour. The cost needed to accomplish this method is RM3000 in which it gives an outcome with a new optimum fan speed value and PCB speed controller.

Secondly, to propose optimum flow directing outlet design (shape and dimension) with respect to air flow rate, the detail works comprises of design and fabricating flow directing outlet whereby the factor to be considered in this case will be the air flow shape and speed. In order to perform this method, sound level meter, drying time, anemometer, and moisture meter will be needed. There are various types of design for the outlet shape whereby all of the design shapes can be produced by using 3D printing for prototyping which gives a various shape design and size as the output. The outcome is a new optimum flow directing outlet design with cost of RM 3500. Please refer to Appendix A for image of the various types of air outlet design shape.

Lastly, to propose additional damping mechanism and noise insulator on the component, the detail works comprises of installing rubber coupling between the motor and fan shaft and also to install rubber motor mounting. In this case, the factors to be considered are the type of material, damping coefficient and size. Apart from that, soundproofing acoustic foam inner cover can also be introduced. The factors to considered in this case will be the type of material, type and shape like pyramid, egg carton, wedges and pyramid. Also, rubber seal can be installed in between the matting part. The total cost required to perform this method is RM1300 provided that the outcome produced are the damping mechanism and noise insulator to minimize vibration and noise. Please refer to Appendix A for the images of rubber coupling and motor mounting and the various soundproofing acoustic foam.

1.5 Importance of Study

According to the experts, any noise level which is higher than 85 decibels is equivalent to a heavy traffic. Thus, there might be chances that long term exposure to this level of noise might causes hearing damage (TRC, 2019). In other words, the risk of hearing loss increases as the decibels increases. Likewise, people who experience long term exposure to extremely loud noises will have a much higher possibility in developing hearing problems. In order to prevent hearing problem, ones should always obey to the general rule of thumb which is to never take in sounds that are above the decibel threshold for longer than two minutes (TRC, 2019).

Nothing is more irritating at work for many people than a lot of noise, whether it comes from outside or inside the house. Excessive occupational noise has a variety of negative effects, including lower efficiency, more difficult communication, permanent hearing loss, and a rise in health conditions and hearing-related injuries among workers (TRC, 2019). To prevent these negative effects, it is important to assess the noise levels at the workplace on a regular basis and fix anything that is too noisy to be disruptive or dangerous. There are a variety of indicators of disruptive workplace sounds, as well as a variety of approaches and control measures. By understanding how the ear functions and the noise levels that are suitable for the workplace while still complying with OSHA are the first steps are very essential to prevent hearing impairment (TRC, 2019).

1.6 Organization of Thesis

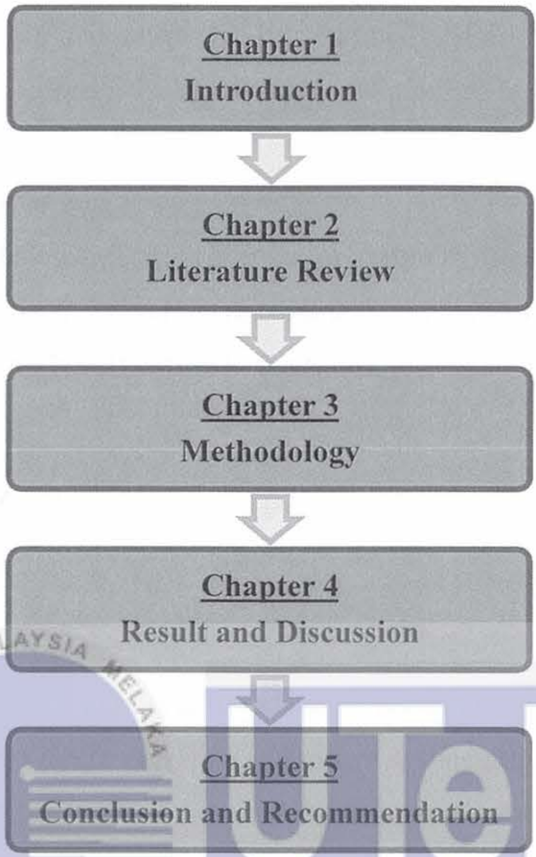


Figure 1.1: flow of the thesis

1) **<u>Chapter 1: Introduction</u>**

   Chapter 1 is all about the introduction of the project which comprises of the background of study, problem statement, objectives, scope, importance of study, organization of the thesis and also the summary.

2) **<u>Chapter 2: Literature Review</u>**

   The literature review in Chapter 2 covers the findings of a variety of sources which include the journals, articles, books, and websites. This chapter will be based on the most recent observations, methods, and outcomes from the relevant journal papers, books, and blogs.

3) **<u>Chapter 3: Methodology</u>**

   In Chapter 3 for Methodology, the procedure and framework of the analysis is being discussed. This involves the experimental apparatus, techniques, and procedures for data analysis will be discussed in the methodology section.

4) **Chapter 4: Result and Discussion**

Chapter 4 is all about result and discussion whereby all the outcomes obtained from conducting the research and study will be compiled and discussed. The outcomes will also be evaluated and address the outcomes that are linked to the objectives.

5) **Chapter 5: Conclusion and Recommendation**

Finally, in the conclusion and recommendation chapter which is also the Chapter 5, the study will be summarised, as well as providing recommendations for future work. This is to boost the product's specification in the future.

1.7 Summary

In conclusion, this project mainly focusing on the hand dryer whereby improvement is needed to be made on the hand dryer to reduce its noise level to the most minimum level without having to sacrifice the drying time and affecting the performance of the dryer's fan. Basically, there are three types of hand dryer fan parameters to be considered in this project which include the fan speed in (rpm), type of insulation and type of nozzle design. The effect of the hand dryer fan parameters on noise and aerodynamic level is the main task that is needed to be determined and tested out in this project.

Hence, a more practicable engineering solution has been proposed whereby an optimum directing outlet design can be made by considering the shape and dimension with respect to the air flow which might work to reduce the noise level of the hand dryer. Besides, an additional damping mechanism and installing noise insulator on the component of the hand dryer may also be a wise option to reduce noise. Apart from that, finding an optimum fan speed at minimum noise level with acceptable drying time is also part of the scope for this project.

If the high fan noise levels are inevitable, then ways to reduce the acoustic energy should be in consideration (Lawrence Berkeley National Laboratory Washington, 2003). There are several methods that can be implemented to reduce noise such as applying layer on insulation to the duct, mounting the fan on a soft material such as rubber or acceptable spring isolator as per required in order to limit the amount of vibration energy transmitted. Besides, installing sound damping material or baffles can also help to absorb noise energy efficiently (Lawrence Berkeley National Laboratory Washington, 2003).

CHAPTER 2
LITERATURE REVIEW

2.0 Overview

In this chapter, there are total of 10 subtopics which review about the noise and control for hand dryer provided with specifications of various types of hand dryers in the market. The content includes the introduction, noise sources identification in hand dryer, alternatives to reduce noise level with various applications, engineering noise control strategies, measures of acoustical materials effectiveness, technical specifications of hand dryers in the market, comparison of the sound intensity of hand dryers, Taguchi method, Full Factorial design, Design of Experiment (DoE) and lastly the summary of the chapter.

2.1 Introduction

Generally, it is crucial to protect human hearing in order to avoid hearing loss and learning disabilities. The truth is, children's ears are more susceptible to harm from high loudness of noises compared to adults. Thus, it is especially important to keep them healthy from any circumstances. The shorter the exposure to a louder sound, the more likely it is to cause hearing harm. Apart from that, sudden loud noises (such as those produced by a hand dryer) are more dangerous than steadily rising noise as the facial nerve has little time to protect the ear by 'dampening' the ear ossicles (bones that transmit sound inside the ear) (Keegan, 2020).

Noise-induced threshold shifts (NITS) is a kind of temporary loss of hearing ability caused by loud noises. In some cases that is encountered with frequent NITS, hearing may be permanently lost (Keegan, 2020). High-speed hand dryers seem to be an engineering major success that aligns into the current recession and sustainable development. However, there is still some cost that need to be bear behind the success story. The rule of the thumb is that the quicker the hand drying process is completed, the louder the sound will be. Furthermore, the concept of "noise as power" has been widely publicized (J. Drever, 2017).

Noise-induced hearing loss is one of the recognised health hazard which is associated with occupational noise. Men should not be subjected to more than 90 decibels in an 8-hour shift, which according to the United States' Occupational Safety and Health Administration (OSHA). According to the National Institute for Occupational Safety and Health (NIOSH), employees should not be exposed to more than 85 decibels (dBA) during an 8-hour workday. Many countries all over the world follow NIOSH's strategy, which is defined based on the WHO recommendations (Liu & Wang, 2019).

2.2 Noise Sources Identification in Hand Dryer

In general, the noise produced by different types of fans in hand dryer application varies from one another. However, the mechanisms for noise are relatively similar. Conceptually, these type of noise can be classified into vibrational noise from structural vibrations such as the assembly of the fan motor and the noise produced from steady or unsteady air flows (Yue, 2016).

2.2.1 Vibrational Noise

Generally, electric motor literally is a mechanical device in which various components interface with forces, motion and power. As suggested by conventional thinking, the emissions of sound and vibration are strictly related, but the connection between the vibration sources and the emitting area is much less apparent (Fasana & Laterra, 2019). The sound radiation emitted by an electric motor involves various stages which comprises the identification and detection of the vibratory sources and of the emitting surface. Electric motor vibration sources can be divided into two principal groups which in terms of the mechanical vibration and electromagnetic vibration. All the disturbance caused by the nonlinear response of the revolving mechanism which triggered by mechanical vibration sources. The most common sources of mechanical vibrations comprise of imbalance, bearings, misalignment, and cooling system (Fasana & Laterra, 2019). The following Table 2.1 shows the description for the causes of each type of sources for mechanical vibration.

Table 2.1: Causes of Each Type of Sources for Mechanical Vibration with Description

No.	Mechanical Vibration Sources	Causes of the Mechanical Vibration Sources
1.	Imbalance	• The system vibrations of an electrical motor are generated by imbalance residual rotor which is inevitable in its nature.
2.	Bearings	• An essential component in the rotating system of an electrical motor. • Bearings may function as a passive element in a transmission path that emits vibrations from the source to the surface or act as an active element which causes vibrations due to the dynamic nature.
3.	Misalignment	• The misalignment of the shaft is usually caused by the coupling with the operation of an electrical system.
4.	Cooling System	• Air ventilation is often supplied by integrated fans to the cooling system of the electrical motor. • Vibrational and acoustic perturbation is introduced by Fan. • The blade motion in the air causes disturbance called airborne sound which affects the dynamic of the rotor.
	Reference: (J. Drever, 2017) Retrieved From: https://webthesis.biblio.polito.it/10747/1/tesi.pdf	

In terms of the electromagnetic sources, all vibrations resulting from the magnetic interaction of the stator and the rotor or from feeding systems are being implied. For instance, a high noise part with a tonal sound at the same time wavelength as the frequency set up by the VFD feeding would be introduced into the system (J. Drever, 2017).

2.3 Alternatives to Reduce Noise Level with Various Applications

In general, there are various alternatives that can be applied to reduce noise level in hand dryers by having the optimum fan speed at minimum noise level with acceptable drying time. These alternatives include the application of insulating foam, sound level meter, soundproof box, and porous material which will be discussed in the following subtopics.

2.3.1 Insulating Foam

Since noise pollution has becoming more significant and concerning in terms of its negative impact especially on human health, thus, one of the best alternative is by implementing sound absorbing material into the application of noise reduction by conducting respective research and development (Tiuc et al., 2016). Hence, polyurethane foam which is also the most common sound absorbing material that has been widely used in industry is well known for its performances in terms of acoustic, electrical, mechanical, and thermal properties (Tiuc et al., 2016).

Various approaches have been documented for the analysis of sound absorption with cavity and pore morphology, pores type, cell-wall area, phase separation, and viscoelasticity in the polyurethane (PU). The flexible PU foams are well known to be used as sound absorbing materials due to their light weight, excellent sound absorption in wide range of frequency and easiness in production (Baek & Kim, 2020). Please refer to Appendix B for the image of Polyurethane (PU) acoustic foam.

2.3.2 Sound Level Meter

Sound level meter (SLM) is a sound pressure level measurement tool. This device can be used as a noise level monitor for sources of noise which can potentially cause ear pain upon long term exposure (Asfiati et al., 2020). Efforts to regulate noise tend to decrease sound amplitude from the source of the noise. In analysing acoustic performance in an enclosure, the sound absorption materials (such as materials that consume any energy on a sound wave event and minimize reflections) and those materials that minimize sound transmission should be distinguished. By using the sound level meter, one can make a better decision by either only control the noise at the source itself or control the noise at each step of the system (David et al., 2013). Please refer to Appendix B for the image of sound level meter.

2.3.3 Soundproof Box

A soundproof box is a space or room made of special materials that prevent sound waves from travelling in both indoors and outdoors. Soundproof boxes are commonly used in situations in which stray noises do not penetrate the room (Ted W, 2020). The main construction of the soundproof box including various soundproofing materials in order to integrate high mass, mechanical decoupling, and absorption (Lysenko et al., 2019). Please refer to Appendix B for the image of soundproof box.

2.3.4 Porous Material

Porous materials incorporate the properties of lightweight, wide frequency absorption and high absorption capabilities of the most frequently used materials, and provide a strong sound absorption capability. Porous materials for sound absorption consist of channels, cracks or cavities that facilitate sound waves to penetrate the materials. Sound energy is dissipated by thermal losses caused by air molecules friction with pores, and the viscous loss of airflow inside the structures is viscous (Cao et al., 2018).

These concepts of energy consumption include a wide frequency range for porous materials to absorb the sound. Porous sound damping materials are also the best material for controlling the noise due to their exceptional effects as low cost, simple moulding and weight reduction (Cao et al., 2018). There are six types of fibrous sound absorption materials which are made of porous materials. These include the natural fibers, synthetic fibers, inorganic foams, hybrid foams, organic foams and inorganic fibers. For more information, please refer to Appendix B for the type of porous material for sound absorption.

2.4 Engineering Noise Control Strategies

In a facility where staff spend hours monitoring noise levels at loud sites, the need to monitor or otherwise in a certain situation is required. If individual employees spend just a fraction of the working day in loud environments, local laws may allow for much higher levels of noise but with condition that the noise levels in places used by employees' ears should be assessed within which appropriate (Professor Colin H. Hansen, 2017). There are several strategies that are suitable for the application of hand dryer noise reduction can be implemented in terms of the engineering noise control. These include the techniques such as the partial enclosure, fan installation and efficiency, fan speed reduction, ductwork, and aerodynamic fan noise control. Each of the techniques will be explained further in the following subtopics.

2.4.1 Partial Enclosure

The Figure 2.5 above shows a partial enclosure barrier setup surrounding the noise source. Generally, the application of sound absorption has been used for a long time to reduce noise. However, in many practical implementations, noise sources cannot be entirely enclosed and gaps must remain for accessibility, cleaning, ventilation and/or heat dissipation even though it has been theoretically proven that a full enclosure is able to achieve the highest noise mitigation efficiency. In this case, partial enclosure is the best alternative in reducing noise radiation, but with condition that the openings must have noise propagation paths, which may potentially affect the efficiency of passive noise reduction. In order to achieve balance between the noise reduction and ventilation, partial enclosure design is the most suitable technique to be used (Wang et al., 2017). Please refer to Appendix B for the image of partial enclosure barrier setup surrounding the noise source.

The Figure 2.6 below shows a graph of sound power reduction (dB) over ratio of covered to total area. The graph explicitly reveals that there can be a propagation loss of approximately 20 dB of the case walls and the most sound power reduction possible is of approximately 10 dB. In certain situations, however, the noise levels can be decreased more significantly, especially in areas directly behind solid sections of the enclosure (Professor Colin H. Hansen, 2017).

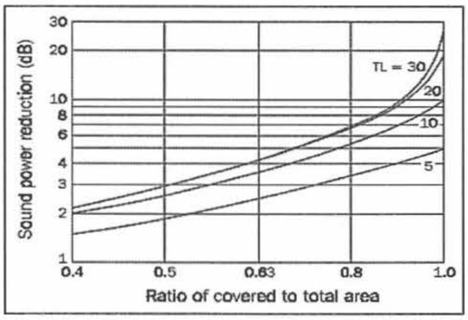


Figure 2.1: Estimate of sound power reduction due to a partial enclosure
Retrieved From: https://www.who.int/occupational_health/publications/noise10.pdf

2.4.2 Fan Installations and Efficiency

The fan installations and efficiency is typically applied on axial flow fan or centrifugal fan. Generally, the structure of the duct position into and out of fans contributes to a very remarkable effect both on the efficiency of the fan and on the noise produced. The turbulence in the air flow which is also a form of wasted energy generates noise. In precise, maximum fan efficiency correlates with minimal noise. By implementing this technique, it helps to increase the efficiency and reduces both the running costs and noise (Wilson, 2017).

In order to achieve optimum fan performance with minimal noise, it is ideal to ensure that there are at least 2 to 3 duct diameters of straight duct between any component that might interrupt the flow and the ventilator itself. In this case, a noise reduction of 3 dB to 12 dB is achievable (Watson, 2016). In addition, a bell mouth intakes can be implemented to provide a smooth intake flow (Wilson, 2017). Please refer to Appendix B for the illustration of axial flow fan installations.

In general, noise increases if there is any fan installation with interface that tends to reduce the fan performance. The most common examples are the bends and damper which gives different outcome in terms of the amount of noise produced by the fan (Watson, 2016). Referring to Appendix B which illustrates the centrifugal fan installations, the bends which are located specifically at the intake side near the fan emits more noises. While the dampers which are located near to the fan intake or exhaust emits less noises and is quieter (Watson, 2016).

2.4.3 Fan Speed Reduction

The Table 2.2 below gives a reference for the dynamic equilibrium between noise and fan speed. For instance, by reducing the fan speed by 20%, the noise level will decrease by 5 dB which approximately contributes to an overall noise reduction of 68%. Fitting the damper right into the outlet for the fan ensures that, in certain vanes, the higher air velocity increases the noise and decreases the efficiency of the fans. Fan noise is approximately proportional to the highest speed of the fan which is the 5th force. In certain cases, the fan speed can then be reduced marginally by multilevel inverter, adjusting the control systems or pulley sizes, and restarting dampers, which allows an achievable significant reduction in noise. At the same time, this procedure can also reduce the operating costs and noise (Wilson, 2017).

Table 2.2: Dynamic Equilibrium Between Noise and Fan Speed

Fan Speed Reduction	Noise Reduction
10%	2dB
20%	5dB
30%	8dB
40%	11dB
50%	15dB

Retrieved From: https://iosh.com/media/2067/noise-and-vibration-chiltern-april-2017.pdf

2.4.4 Ductwork

Instead of installing a silencer, an acoustic absorbent (foam or rockwool / fibreglass) decrease of 10dB to 20 dB is often achieved when the airborne noise is reduced from the duct or opening. Please refer to Appendix B for the image of acoustic barrier for ducting. Alternatively, a simple absorbent lined right-angled bend can be constructed to match the opening. Theoretically, the length of both sides of the bend should be twice the diameter of the duct. If the fluid rate is high which is more than 3 m/s, the cloth faced absorbent can consider to be used. In this case, the vibration of the ducts will normally be damped (Watson, 2016).

Besides, another alternative that can be implemented is by insulating the ducts with liners. Lining the internal surface of the duct to improve the efficiency and damping sound of the device provides both useful insulation. The desired level of insulation and sound reduction can be achieved easily and low in cost by only cutting fabric-covered heat-proof foam for the internal surface of the ducts. A variety of thicknesses for the ducts can be found since foam is a common soundproofing material. Soundproofing is a safer way to avoid noise compared to sound absorption, since the material prevents sound from passing through the ducts and the walls into others space (Bill Ronca, 2016).

2.4.5 Aerodynamic Fan Noise Control

In some cases, fan designs and installations might emit sound and wideband noise. Tonal noise is mostly not just a matter of occupational noise, but rather both from a general viewpoint and "nuisance" which can also consider as an environmental noise issue. The refurbishment aerodynamic and acoustic elements inside fan boxes and their related ductwork are based on aerodynamic noise reduction techniques. The advantages of using this technique is that it is generally low in cost, fast, hygienic and is able to increase the fan efficiency (often 10% - 25% improvement over conventional silencing) provided with rugged (no maintenance for the life of the fan) (Wilson, 2017).

Not only is this aerodynamic fan noise control technique cheap, but it also can lead to a substantial increase in fan efficiency in comparison with traditional silencer. As well as it can be worth fitting for efficiency improvements in comparison to the unmodified fan even if noise is a problem. While this method is based on technical expertise both for modifying and for prediction mitigation, it is not only able to reduce cost significantly but also reduce energy consumption, as well as the knowledge that this award-winning Quiet Fan Technology is usable (Wilson, 2017).

Since fan noise is the amount of the turbulence produced in the air from the blades, several aerodynamical inserts are installed inside the fan housing to smoothen the flow. This decreases pressure fluctuations and therefore leads to noise reduction at the source without the back pressure associated with the silencers being introduced. Not only the noise can be eliminated from the intake and exhaust duct travelling down (typically 10dB–20dB), but also the noise from the fan casing. The need for silencer as well as the acoustic enclosures or lagging will no longer be needed (Wilson, 2017).

This technique will in fact increase fan performance in a large proportion of cases, which ensures that it pays for its own costs. Furthermore, due to the extreme low-frequency noise at source, it is also possible to incorporate low-cost, purpose-designed acoustic elements into existing ducts and stacks, which provide a considerable noise reduction for about10dB to 30dB (Wilson, 2017).

2.4.6 Rubber Motor Mounting

In general, the rubber motor mount is used to stabilised and secure the engine in place. The advantages of using an elastomer-based mount is that it can minimize the vibration produced by the fan motor engine. Besides, the rubber motor mounting can also be used as a spring between the motor engine and the housing of the hand dryer, in which it can minimize the chances of exposing the engine to wear and tear. Furthermore, noise reduction from the fan motor engine can takes place by implementing the rubber motor mounting as an application of noise reduction (Poly-Tek, 2018). Please refer to Appendix B for the image of rubber motor mounting.

2.4.7 Increase the Number of Fan Blades

Based on research, there are several blade design modifications that aids in noise reduction in which one of it is by increasing the number of fan blades (Peixun Yu, Jiahui Peng, Junqiang Bai, Xiao Han, 2019). According to the study conducted by (Adeeb et al., 2015), differences in terms of the volumetric flow rate, mass flow rate and energy efficiency can be observed when different numbers of fan blades are tested. The result shows that when the number of blades increases, the volumetric flow rate and the mass flow rate will also increase. In contrast, the energy efficiency will decrease when the number of fan blades increases. For more information, please refer to Appendix B for the image concept for the number of fan blades increased from 5 blades to 12 blades, bar chart for the volumetric flow rate vs. number of blades, mass flow rate vs. number of blades and also energy efficiency vs. number of blades, respectively.

2.5 Measures of Acoustical Materials Effectiveness

There are many acoustic specifications of acoustical material which are measured and defined by suppliers. The materials are commonly used to quantify the material effectiveness in sound or noise handling. The most common measures are including the absorption coefficient, specific acoustic impedance, Noise Reduction Coefficient

(NRC), Sound Transmission Class (STC) and A-Weighting. The explanation of each measures are covered in the following subtopics.

2.5.1 Sound Absorption Coefficient

The sound absorption coefficient indicates the amount of energy removal from the sound wave when the wave travels through a certain material thickness. The figure 2.10 above shows the schematic diagram of the sound absorption and reflection of an insulated wall. The acoustic wave could experience a reflection or absorption that loses energy and has damping effects as it propagates from air to an absorbing substrate. Sound absorption occurs by the transformation of sound waves into heat in a polymeric material. Hence, sound absorption is essential to achieve the effect of soundproofing (Shrivastava, 2018). Please refer to Appendix B for the schematic diagram of sound absorption and reflection of an insulated wall.

2.5.2 Specific Acoustic Impedance

Specific acoustic impedance is described as a ratio of complex sound pressure amplitude respective to the related defined vector part of the particle velocity. If the field of sound at the interface between various media is concerned, the appropriate particle velocity portion will be normally guided to the interface (Fahy, 2001).

2.5.3 Noise Reduction Coefficient (NRC)

The noise reduction coefficient (NRC) parameter is one of the tool used to measure and compare the acoustic behaviour of various materials by calculating the average of the measured sound absorption coefficients at various levels of frequencies. The NRC values are used as indexes of the sound absorbing efficiency of various materials which provide simple quantification of sound absorption (Hassanzadeh et al., 2014). For more information, please refer to Appendix B for the table of noise reduction coefficient (NRC) ratings.

2.5.4 Sound Transmission Class (STC)

The sound transmission class (STC) is a sound isolation rating of a construction wall assembly. The higher the rating of the STC, the better the wall assembly sound isolation is. STC is commonly used to measure internal barrier, ceilings/floors, doors and walls. Moreover, the STC rating figure illustrates the noise reduction in decibel that can be delivered by the assembly (Chiu et al., 2015). For more information, please refer to Appendix B for the graph of Sound Transmission Class (STC).

2.5.5 A-Weighting

The A-Weighting of a desired noise spectrum for an overall level of 90 dBA to shows a total degree of 90dBA in order to indicate the optimal (less annoying) octave frequency range for the position of the exposed worker. If the target amount is 85 dBA after monitoring, the whole curve must be moved down by 5 dB. The curve is used to calculate the spectrum levels of octave bands and to map results for each octave band onto the graph. Of course, sometimes the optimal noise spectrum is impossible to obtain, but at least it offers a goal for it (Professor Colin H. Hansen, 2017). For more information, please refer to Appendix B for the graph of A-weighting of a desired noise spectrum.

2.6 Technical Specifications of Hand Dryers in the Market

Table 2.3: Technical Specifications of Hand Dryers in the Market

No.	Brand	Model	Optional	Dry	Motor				Sound Power	Nozzle
			Features	Time (s)	Air Flow Rate (CFM)	Air Velocity (LFM/MPH)	Fan Speed (RPM)	Electrical Power (W)	Level (dB)	Size (Inch)
1.	Excel	XLERATOR	HEPA Filter Sound Control Kit (Motor Adjustment)	8 s	39 - 64 CFM	12,000 - 20,000 LFM (at Air Outlet)	Up to 24,000 RPM	1,450 W (Heat On) - 510 W (Heat Off)	77 dB to 82 dB (1.1″ noise reduction nozzle installed to reduce sound level by 9 dB by significantly decreasing noise of air deflection while only increasing dry time by approximately 3 s.)	1.1″
		XLERATOReco (ECO No Heat)	HEPA Filter Sound Control Kit (Motor Adjustment)	10 s	43 - 65 CFM	13,000 - 20,000 LFM (Adjustable)	Up to 24,000 RPM	425 W - 530 W	65 dB to 75 dB (1.1″ noise reduction nozzle installed to reduce sound level by 9 dB by significantly decreasing noise of air deflection while only increasing dry time by approximately 3 s.)	1.1″

		THINAIR	ADA Compliant Adjustable Sound and Speed On / Off Heat Option	14 s	29 - 42 CFM	12,000 - 17,000 LFM	20,000 to 30,000 RPM	(Heat On: 735 W - 950 W) (Heat Off: 300W - 385 W)	69 dB - 76 dB (Adjustable level of sound)	Integral
Retrieved From: https://www.greenelectricalsupply.com/extreme-air-comparison-xlerator-airmax-jet-towel.aspx										
2.	Dyson	Dyson Airblade V	HEPA filter (Glass fibre and fleece prelayer) 99.9% of particles captured	12 s	59.3 CFM	420 MPH	92,000 RPM	1,000 W digital brushless motor	85 dB	0.02″
		Dyson Airblade dB	HEPA filter (glass fibre and fleece prelayer) Bacteria removal 99.9%	10 s - 12 s	63.6 CFM	430 MPH	90,000 RPM	1,600 W digital motor V4 (brushless DC Motor)	81 dB	0.03″
		Dyson Airblade Wash+Dry	HEPA filter (glass fibre and fleece prelayer) Captures 99,95% of particles the size of bacteria from the washroom air	14 s	44 CFM	341 MPH	92,000 RPM	1,400 W	81 dB	0.03″
Retrieved From: https://www.dyson.com/commercial/hand-dryers https://www.dyson.com.au/for-business/overview/specifications-and-documents https://www.lb.dyson.com/en-LB/hand-dryers/useful-documents.aspx										
3.	American Dryer	eXtremeAir GXT	Adjustable Motor for Quieter Operation	10 s - 12 s	130 CFM	19,000-10,000 LFM	24,000 rpm	1500 W - 800 W (Adjustable)	83 dB - 69 dB	Indestructible one-piece fixed nozzle

		eXtremeAir EXT	Adjustable Motor for Quieter Operation (No Heating Element)	12 s - 15 s	160 CFM	19,000-10,000 LFM	24,000 rpm	500 W - 300 W	83 dB - 69 dB	Indestructible one-piece fixed nozzle
		eXtremeAir CPC	Adjustable Motor for Quieter Operation (Uses Cold Plasma Clean Technology to Kill 99.6% of all Germs)	10 s - 12 s	180 CFM	19,000-10,000 LFM	24,000 rpm	1500 W - 800 W (Adjustable)	83 dB - 69 dB	Indestructible one-piece fixed nozzle
Retrieved From: https://www.patientsafetyusa.com/resources/brochure/american-dryer-cold-plasma-clean-hand-dryer-learn-more										
4.	Mitsubishi Electric	Jet Towel	Meet The Hand Dryer That Saves 1.4 Million Trees Per Year (Dual jet airflow drying)	13 s - 15 s	(High Speed: 110 CFM) (Low Speed: 100 CFM)	20,680 LFM	14,000 to 81,000 RPM	(High speed and heat: 1250 W) (Low speed and no heat: 570 W)	58 dB	5.9″
Retrieved From: https://www.handdryer.com/products/mitsubishi-jet-air-hand-dryer-towel-jt-sb116jh-g-na-quiet-ultra-fast-slim-quiet										
5.	World Dryer	SMARTdri	Can Turn Heat On or Off (Adjustable 3 Speed Motor)	10 s - 12 s	45.91 CFM	Up to 23,320 LFM	12,000 to 23,400 RPM	400 W (Eco mode) to 1200 W (Turbo setting)	73-85 DB at operator ear (hands) 61-73 DB at 2 meters (no hands)	Multiport nozzle / Focused high-intensity nozzle
		Airforce	94.9% saving against paper towels (Unique jet configuration –	12 s	105 CFM	10,500 LFM	34,000 RPM	1100 W	83 dB	Innovative multi-port diffuser nozzle

			provide gentle and pleasant massaging effect on the hands)							
		SlimDri	-	15 s	70 CFM	12,320 LFM	13,000 RPM	950 W	80 dB-85 dB	High-intensity single-port nozzle
		VERDEdri	ADA Compliant HEPA Filtered Adjustable Speed 225 MPH	12 s	64 CFM	225 MPH		1500 W	82 dB	High-intensity single-port nozzle
Retrieved From: https://www.prodryers.com/hand-dryer-review-comparison/										

2.7 Comparison of the Sound Intensity of Hand Dryers

An experiment was conducted by Shari Salzhauer Berkowitz to measure and compare the sound intensity of different models of hand dryers that can be readily found in the market. Three famous brands of hand dryers were selected to conduct the experiment which include the brands such as the Dyson, World Dryer and Excel Dryer. The models of hand dryers that has been experimented for the Dyson, World Dryer and Excel Dryer are the Airblade, Airforce and XLERATOR, respectively. The noise level was measured at a distance of 2.5 ft, 5 ft, and 10 ft. All measurements were taken with a digital sound level meter (Berkowitz, 2015).

The mean of the average three measurements of sound level at each distance from the source has been determined for each of the eight hand dryers Please refer to Appendix B for more information on the measurements of sound intensity in dBA and the average sound intensity in dBA for hand dryers in eight bathrooms. On the basis of reverse square law, at every one would assume a drop of 6 dBA doubling the distance but that was not the case. The average strength at each distance for all the readings was also measured at 2,5 ft (from the dryer) with 87 dBA, 5 ft with 84dBA and 10 ft with 82dBA. The highest sound of all the trials was 91 dBA while the lowest sound was 80 dBA which is the Excel Dryer's XLERATOR model hand dryer (Berkowitz, 2015).

2.8 Optimum Flow Directing Outlet Design

The most ideal design of the flow directing outlet or also known as the air outlet nozzle is the wave-shaped slit air nozzle. The wave-shaped slit air nozzle is capable to provide optimum air flow and at the same time reducing noise produced by the hand dryer itself without affecting the drying performance of the hand dryer. Please refer to Appendix B for the image of the section view of wave-shaped slit air nozzle and the Mitsubishi Electric Jet Towel air nozzles, respectively. Since the design of the nozzle is wave like shape, thus the chances of having foreign substances from entering the internal of hand dryer from the nozzle hole is very minimal (Masao Akiyoshi, Fumikazu Matsuura, 2011). Besides, the wave-shaped slit air nozzle helps in reducing the turbulence and noise which is normally created by the two opposing air sheets at both sides of the nozzle outlets. At the same time, the adjustments can also reduce noise level by 1 dB (Butler, 2019). This type of air nozzle is similar to the one that is being used in the Mitsubishi Electric Jet Towel hand dryer model.

2.9 Full Factorial Design

Full factorial design is an experiment that comprise of possibility for all combinations of levels for all factors. In full factorial design, the total number of experiments is determined by the number of factors "k" at the particular level. For example, the total number of experiments at 2-levels with k factors is 2^k. Commonly, the 2^k full factorial design will be used especially when the number of process parameters or design parameters (or factors) is less than or equal to 4 particularly during the early stages of experimental work. The factors at 2-levels is assumed to have an approximately linear response over the range of the chosen factor settings. In the 2^k series of full factorial design, the first design to be studied comprises of one with only two factors such as factors A and B whereby each factor to be studied at 2-levels. In this case, it is known as a 2^k full factorial design. Thus, there will be 4 runs of experiment in total. Please refer to Appendix B for the concept of full factorial design.

2.10 Design of Experiment (DoE)

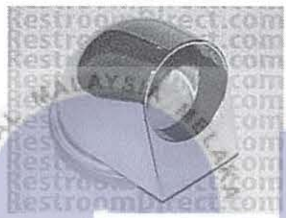
Design of Experiment is a subset of applied statistics concerned with the planning, execution, analysis, and interpretation of standardised experiments in order to determine the variables that influence the significance of a parameter or set of parameters. Design of Experiments (DoE) is also known as Designed Experiments or Experimental Design in which both of these words are interchangeable. Experimental design is often being used at the outstanding level which can potentially minimize the design costs by accelerating the design process, avoiding late engineering design adjustments, and simplifying product materials and labour. Also, Designed Experiments can help to save money in the manufacturing process by reducing rework, scrap, and inspection time (*Design of Experiments (DOE) Tutorial*, n.d.). Please refer to Appendix B for the flowchart of experimental design process of DoE.

2.11 Input Parameters to be Studied

In this project, there are three input parameters to be studied in order to obtain the best output response. The input parameters include the type of nozzle and type of insulation. The details of each input parameters will be elaborated in the following subtopics.

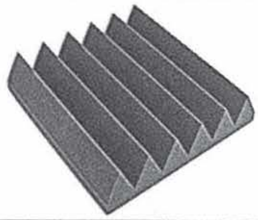
2.11.1 Type of Nozzle Design

Table 2.4: Type of nozzle design

Input Parameter	Level 1	Level 2	Level 3
Design	A	B	C
Name of Nozzle	Chrome Nozzle	Concentrator Nozzle	Diffuser Nozzle
Images			
Features	• Wide and rounded end outlet with maximum airflow rate.	• Elongate slot-shaped outlet. • Combination of Design A and Design C for the air outlet with moderate airflow rate.	• Narrow slot-shaped outlet with minimum airflow rate.
Specifications	• High Volume • Low Velocity Jetting • Very high noise level • Sound pressure level at 82 dBA • Drying time at 30 s to 50 s. • Directs drying air down onto user's hand • Low air speed • Inefficient drying	• Medium Volume • Medium Velocity Jetting • Low noise level • Sound pressure level at 68 dBA • Concentrate the airflow towards a selected portion to be dried.	• Low Volume • High Velocity Jetting • High noise level • Sound pressure level at 75 dBA • Strong air coming out from the nozzle outlet • High air speed • Efficient drying • The inner surface of the nozzle is designed with blended curve profile that helps in minimising any turbulence or recirculation of the airflow within the nozzle.
Citation	• (Jeffrey Fullerton, 2016) • (Michael Ryan, 2017)	• (Stephens, 2018) • (*Swiss Bébé*, 2013)	• (Elizabeth et al, 2019) • (Josephine, 2021)

2.11.2 Type of Insulation

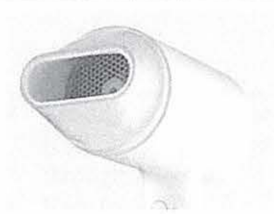
Table 2.5: Type of insulation

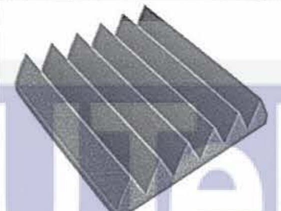
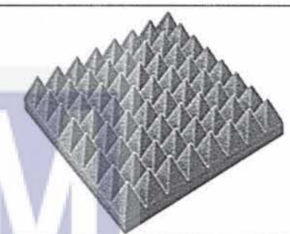
Input Parameter	Level 1	Level 2	Level 3
Design	A	B	C
Shape	Egg Carton	Wedge	Pyramid
Images			
Features	• Dimpled form design surface that can used to absorb shock and stress.	• Open cellular structure (allow sound wave to enter and trap within the foam).	• Similar to the wedge but with pointed tip that appear like pyramids on the surface of the foam.
Functions	• Used to store and transport whole eggs. • Not designed for any acoustic purpose.	• To enhance acoustical dynamics. • To minimize reverberations.	• To trap and absorb sound energy effectively. • To enhance acoustical dynamics. • To minimize reverberations.
Advantages	• Inexpensive (can use be recycled and reuse after buying eggs) • Readily available • Easy to install • Lightweight • High durability	• Readily available (can purchase through Internet) • Easy to install • Excellent noise insulation • Excellent noise absorption • Lightweight • High durability	• Readily available (can purchase through Internet) • Easy to install • Good noise insulation • Good noise absorption • Lightweight • High durability • Supports direct sound • Reduce sound reflection to the wall
Limitations	• Poor noise insulation • Poor noise absorption	• Expensive (especially purchasing in batch)	• Expensive (especially purchasing in batch) • Noise absorption will eventually decreased along the "in-depth shaping process" as there is fewer foam material on the tiles due to its shape unlike the wedge foam.
Citation	• (Quintero Rincon Antonio, 2010) • (Satwiko et al., 2017) • (Galic et al., 2018)	• (Dominic, n.d.) • (Randolph Hoover, 2015) • (Tsay & Yeh, 2019) • (Wedge Tiles, n.d.)	• (Dominic, n.d.) • (Randolph Hoover, 2015) • (Order Pyramid Foam Materials Online, 2021) • (Different Types of Acoustic Foam | Foam Factory, Inc., n.d.) • (Wertel, 2000)

2.12 Summary

In summary, the effect of hand dryer fan parameter on noise and aerodynamic level can be experimented by using the Design of Experiment (DoE) approach by implementing the Full Factorial Design method. The factors to be considered are including parameters such as the type of nozzle design and type of insulation. The main aim of the experiment is to study and obtain the best relationship between these two parameters which is to have high fan speed, minimum level of noise, and short drying time. While the responses to be observed in this experiment will be the air velocity (MPH), noise level in (dB) and drying time in (s). The Table 2.6 below shows the summary of Chapter 2 Literature Review.

Table 2.6: Summary of Chapter 2 Literature Review

Constant Variable			
Category	Maximum Level		
Fan Speed (rpm)	15,000		
Response	• Maximum airflow • High noise level • Short drying time • Efficient drying		
Citation	• (Desvard et al., 2014) • (Corinne Zudonyi, 2017)		
Input Parameter 1	Level 1	Level 2	Level 3
Design	A	B	C
Name of Nozzle	Chrome Nozzle	Concentrator Nozzle	Diffuser Nozzle
Images			
Features	• Wide and rounded end outlet with maximum airflow rate.	• Elongate slot-shaped outlet. • Combination of Design A and Design C for the air outlet with moderate airflow rate.	• Narrow slot-shaped outlet with minimum airflow rate.
Specifications	• High Volume • Low Velocity Jetting • Very high noise level • Sound pressure level at 82 dBA	• Medium Volume • Medium Velocity Jetting • Low noise level • Sound pressure level at 68 dBA	• Low Volume • High Velocity Jetting • High noise level • Sound pressure level at 75 dBA

	• Drying time at 30 s to 50 s. • Directs drying air down onto user's hand • Low air speed • Inefficient drying	• Concentrate the airflow towards a selected portion to be dried.	• Strong air coming out from the nozzle outlet • High air speed • Efficient drying • The inner surface of the nozzle is designed with blended curve profile that helps in minimising any turbulence or recirculation of the airflow within the nozzle.
Citation	• (Jeffrey Fullerton, 2016) • (Michael Ryan, 2017)	• (Stephens, 2018) • (*Swiss Bébé*, 2013)	• (Elizabeth et al, 2019) • (Josephine, 2021)
Input Parameter 2	Level 1	Level 2	Level 3
Design	A	B	C
Shape	Egg Carton	Wedge	Pyramid
Images			
Features	• Dimpled form design surface that can used to absorb shock and stress.	• Open cellular structure (allow sound wave to enter and trap within the foam).	• Similar to the wedge foam but with pointed tip that appear to be like pyramids on the surface of the foam.
Functions	• Used to store and transport whole eggs. • Not designed for any acoustic purpose.	• To enhance acoustical dynamics. • To minimize reverberations.	• To trap and absorb sound energy effectively. • To enhance acoustical dynamics. • To minimize reverberations.
Advantages	• Inexpensive (can use be recycled and reuse after buying eggs) • Readily available • Easy to install • Lightweight • High durability	• Readily available (can purchase through Internet) • Easy to install • Excellent noise insulation • Excellent noise absorption • Lightweight • High durability	• Readily available (can purchase through Internet) • Easy to install • Good noise insulation • Good noise absorption • Lightweight • High durability • Supports direct sound • Reduce sound reflection to the wall
Limitations	• Poor noise insulation • Poor noise absorption	• Expensive (especially purchasing in batch)	• Expensive (especially purchasing in batch) • Noise absorption will eventually decreased along the "in-depth shaping process" as

			there is fewer foam material on the tiles due to its shape unlike the wedge foam.
Citation	• (Quintero Rincon Antonio, 2010) • (Satwiko et al., 2017) • (Galic et al., 2018)	• (Dominic, n.d.) • (Randolph Hoover, 2015) • (Tsay & Yeh, 2019) • (*Wedge Tiles*, n.d.)	• (Dominic, n.d.) • (Randolph Hoover, 2015) • (*Order Pyramid Foam Materials Online*, 2021) • (*Different Types of Acoustic Foam | Foam Factory, Inc.*, n.d.) • (Wertel, 2000)

CHAPTER 3
METHODOLOGY

3.0 Overview

In this Chapter 3 Methodology, students are required to choose appropriate methodology to solve for the complex engineering problem based on the relevant findings that has been obtained based on the literature review. In this case, the most appropriate methodology to conduct this project is by implementing the Design of Experiment (DoE) by using the Full Factorial Design approach. The following subtopics will discuss further in detail about the overview and method of conducting the experiments.

3.1 PSM 1 Gantt Chart

The following Table 3.1 and Figure 3.1 shows the Gantt chart for PSM 1 provided with the detail start date and task duration, respectively. There are 16 tasks in total to be completed during the PSM 1 for 14 weeks of duration. The tasks to be completed are including the PSM 1 title registration, understanding PSM 1 title, draft proposal report, PSM 1 log book writing, Chapter 1 progress writing, Chapter 2 progress writing, Chapter 3 progress writing, reference and formatting, compile PSM 1 Final Report, PSM 1 log book submission, prepare presentation slide, prepare presentation video, PSM 1 online presentation, final report submission, general conduct meeting, and PSM 2 project planning.

During this semester, student had taken 1 day to complete for each tasks which include the PSM 1 title registration, PSM 1 log book submission and final report submission. All three of these tasks were to be completed on the exact same day with no further delay. On the other hand, student only used 2 days to complete the tasks such as the reference and formatting, compilation of PSM 1 final report and preparation for presentation slide. To draft the proposal report, prepare presentation video and planning for the PSM 2 project, student only used 3 days to complete. As for understanding the PSM 1 title, perform Chapter 1 progress writing and conduct PSM 1 online presentation, the duration taken was 4, 5 and 6 days, respectively.

Apart from that, the Chapter 3 progress writing took 20 days which is approximately 3 weeks for student to complete. While it took 27 days for student to complete the Chapter 2 progress writing. Of all the tasks to be completed during the PSM 1 in this semester, the task that has taken the longest duration to be completed is the general conduct meeting (95 days) and next followed by the PSM 1 log book writing (74 days). The general conduct meeting was held throughout the whole semester from Week 1 until Week 14 with the participation of both the student and supervisor of the project. Whereas the PSM 1 log book writing was done continuously from Week 1 until Week 11.

Table 3.1: Task description for PSM 1 Gantt chart

Task Description	Start Date	End Date	Task Duration (Days)
PSM 1 Title Registration	3/15/2021	3/16/2021	1
Understanding PSM 1 Title	3/15/2021	3/19/2021	4
Draft Proposal Report	3/22/2021	3/25/2021	3
PSM 1 Log Book Writing	3/15/2021	5/28/2021	74
Chapter 1 Progress Writing	3/29/2021	4/4/2021	6
Chapter 2 Progress Writing	4/5/2021	5/2/2021	27
Chapter 3 Progress Writing	5/3/2021	5/23/2021	20
Reference and Formatting	5/24/2021	5/26/2021	2
Compile PSM 1 Final Report	5/26/2021	5/28/2021	2
PSM 1 Log Book Submission	5/28/2021	5/29/2021	1
Prepare Presentation Slide	5/31/2021	6/2/2021	2
Prepare Presentation Video	6/2/2021	6/5/2021	3
PSM 1 Online Presentation	6/7/2021	6/12/2021	5
Final Report Submission	6/14/2021	6/15/2021	1
General Conduct Meeting	3/15/2021	6/18/2021	95
PSM 2 Project Planning	6/15/2021	6/18/2021	3

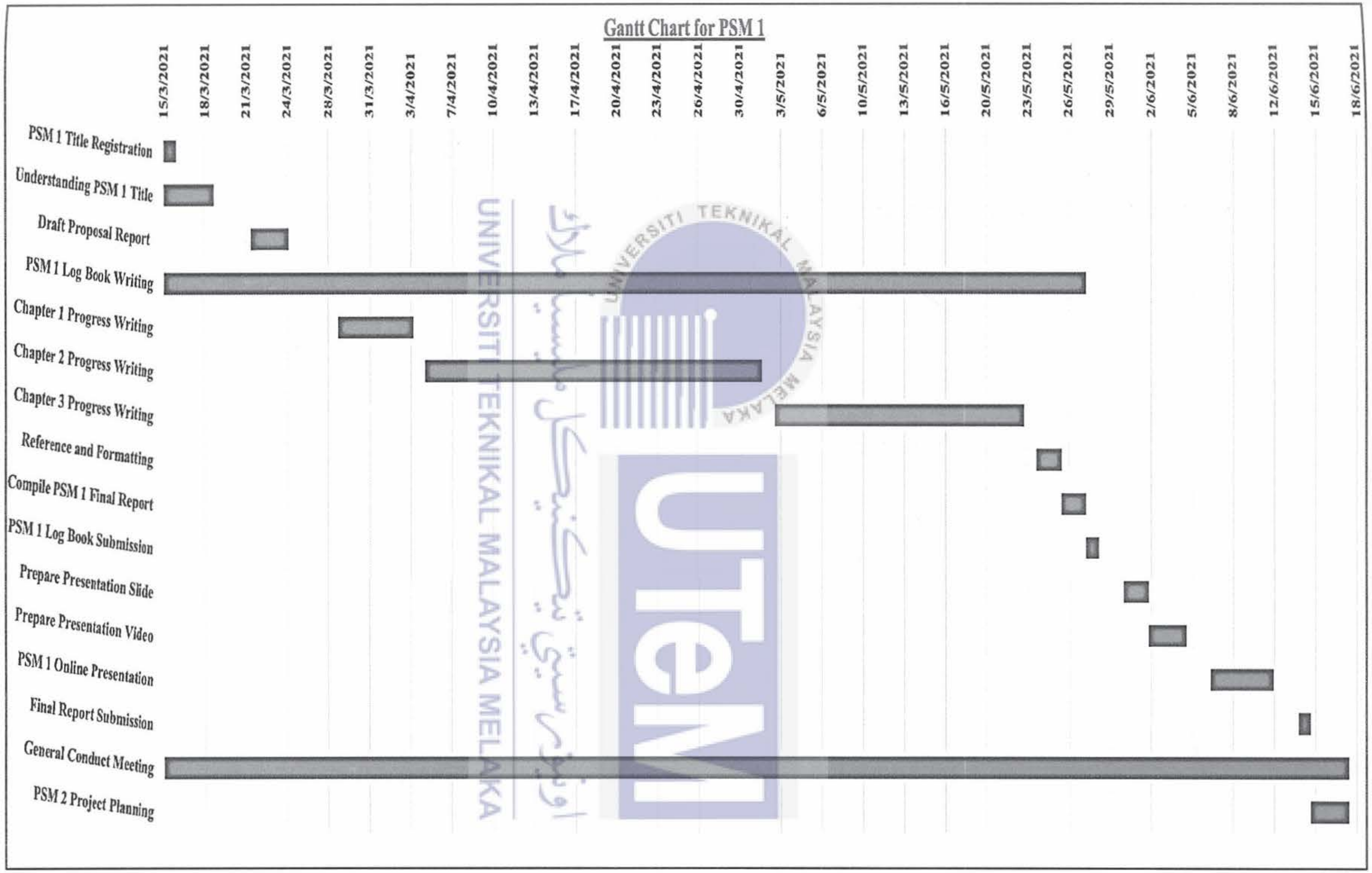


Figure 3.1: PSM 1 Gantt chart

3.2 Research Methodology Overview

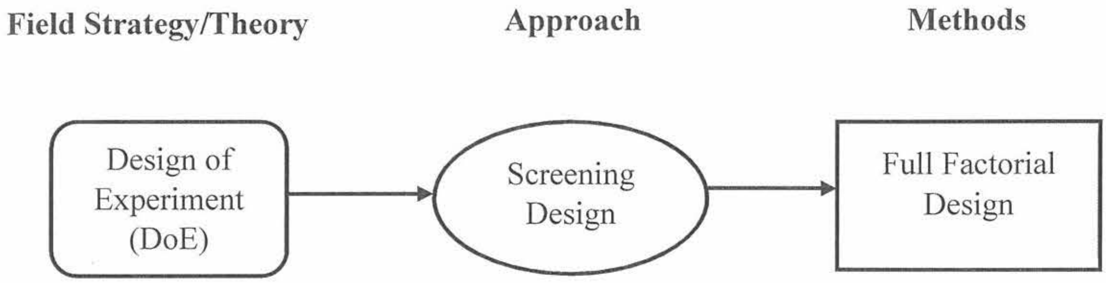


Figure 3.2: Research methodology overview

Figure 3.2 above shows the overview of the research methodology used in this project. The field strategy or known as theory that is applied in conducting this project is the Design of Experiment (DoE). The approach that is implemented for this project is the Screening Design while the method of conducting the experiment is by using the full factorial design. (*Design of Experiments (DOE) Tutorial*, n.d.).

3.2.1 Design of Experiment (DoE)

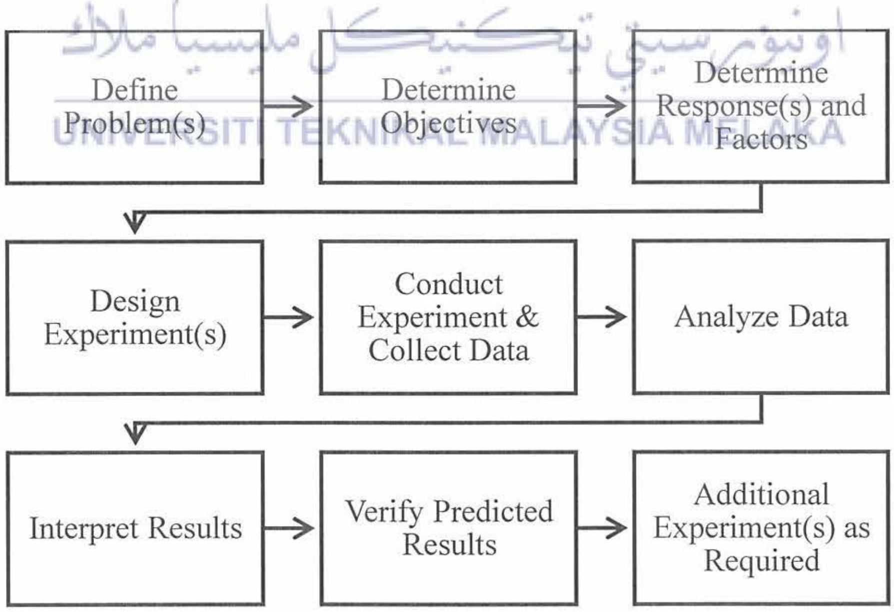


Figure 3.3: Experimental design process
Retrieved From: https://www.moresteam.com/toolbox/design-of-experiments.cfm

Design of Experiment is a subset of applied statistics concerned with the planning, execution, analysis, and interpretation of standardised experiments in order to determine the variables that influence the significance of a parameter or set of parameters. Design of Experiments (DOE) is also known as Designed Experiments or Experimental Design in which both of these words are interchangeable. Experimental design is often being used at the outstanding level which can potentially minimize the design costs by accelerating the design process, avoiding late engineering design adjustments, and simplifying product materials and labour. Also, Designed Experiments can help to save money in the manufacturing process by reducing rework, scrap, and inspection time (*Design of Experiments (DOE) Tutorial*, n.d.).

3.2.2 Screening Design

Screening designs are a productive way to analyse a huge range of process or design parameters (or factors) in a small number of tests or trials (i.e. with minimum resources and budget) (Antony, 2014). Besides, screening designs can also be used to determine the most critical parameters that will have a direct effect on the performance of the process. In most cases, full factorial designs along with the fractional factorial designs and the response surface methods may be used to understand and analyse the significance of interactions among the main parameters once they have been detected (Antony, 2014).

3.2.3 Full Factorial Design

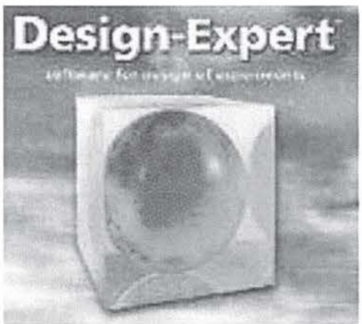


Figure 3.4: Design Expert statistical software

A full factorial design examines any possible mixture of factors and also the level of factors. These responses are tested to determine each key effect and interaction effect. Although less than five variables are being studied, a full factorial design is more practical and convincible. With five or more variables, testing all variations of factor thresholds becomes too costly and time-consuming. In this project, the factors to be considered are including parameters such as the type of nozzle design and type of insulation. While the fan speed of the hand dryer is fixed at 15,000 rpm.

Since there are two factors to be considered in this project with each factors have three levels. Thus, the 3^2 full factorial design is the most suitable method to be used in which total number of 9 experiments will be conducted provided with 2 factors (parameters) at 3 levels. The main aim of the experiment is to study and obtain the best relationship between these three parameters which is to have maximum airflow, minimum noise level and shortest drying time. The software that is used to conduct the full factorial design experiment is by using the Design Expert software.

3.3 Flowchart of the Project

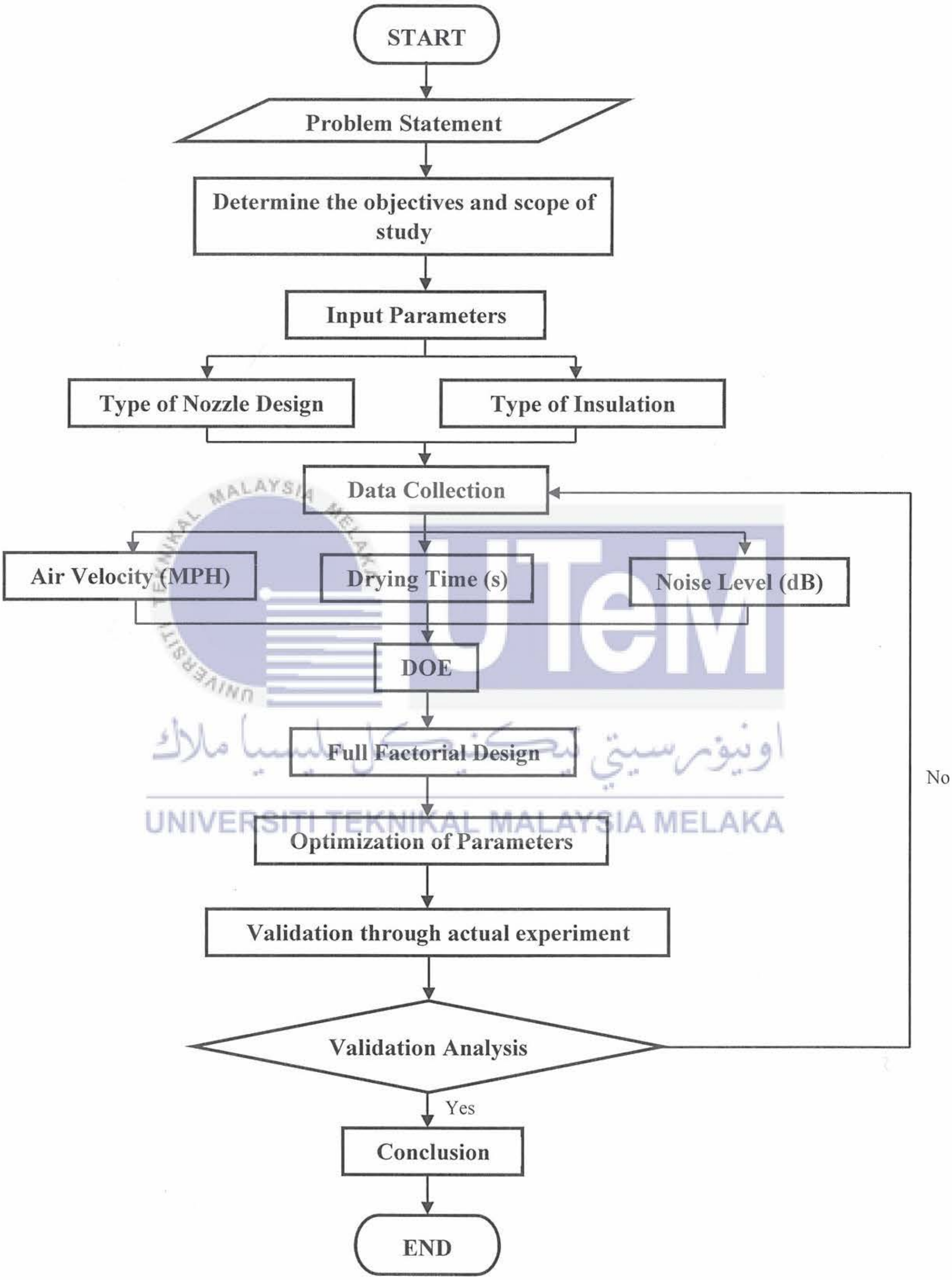


Figure 3.5: Flow chart of the project

Figure 3.5 above shows the flow chart of this project. The flow chart is a representation that can provide a clear view of the overall process or activities that will be carried out in this project. The overall process of the project is shown in a graphical manner whereby the sequence of the project started from the first step until the final step which is also the end of the process. In this project, there are total of 10 main steps to conduct the experiment which comprises of the problem statement, determine the objectives and scope of the study, input parameters, data collection, Full Factorial Design, optimization of parameters, validation through actual experiment, validation analysis and lastly the conclusion.

First, the flow chart started with the analysis of the problem statement for the project. Second, the objectives and scope of study are determined. Third, the input parameters of the project are being identified which including the type of nozzle design and type of insulation. After the parameters have been identified, data collection will be proceeded with DoE and if otherwise, input parameters will be restudied. At the data collection stage, the data to be collected which is also the responses from the hand dryer based on the input parameters which are the air velocity (MPH), noise level in (dB) and the drying time in (s) under the condition of constant variable which is the fan speed of the hand dryer fixed at the rate of 15,000 rpm.

The method of conducting the experiment for the data collection is by using the Full Factorial Design which is one of the tool from Design of Experiment (DoE). After all the simulations and data collection have completed, the results will be validated through actual experiment in order to obtain the minimum noise level and fastest drying time provided with maximum airflow of the hand dryer by optimizing the parameters. Lastly, conclusion will be drawn after the results and discussion has been obtained.

3.4 Process of Developing Nozzle Design

In this project, the process of developing the nozzle design is particularly important and is required to be completed prior to the stage of conducting the actual experiment and Design of Experiment (DoE). Based on the literature review from Chapter 2, there are three types of nozzle design that have been proposed to support and study the effect of hand dryer fan parameter on noise and aerodynamic level. The type of nozzle design includes the chrome nozzle, concentrator nozzle and diffuser nozzle. Before conducting the experiment, all three type of nozzles were designed by using the SolidWorks software and then proceeded to 3D printing process by using Acrylonitrile Butadiene Styrene (ABS) plastic as the main material. The outcome of the process are as shown in Appendix D.

3.5 Experimental Layout Plan

The experimental layout plan of the full factorial design of the experiment to test the effect of hand dryer fan parameter on noise and aerodynamic level was carried out by using the Design Expert software. As mentioned in the earlier subtopic, the factors to be considered are including parameters such as the type of nozzle design and type of insulation. While the responses to be observed in this experiment will be the air velocity (MPH), noise level in (dB) and the drying time in (s). Both the input parameters to be experimented will be referring to the Table 2.7 provided in the previous Literature Review under the Chapter 2.

All two inputs of the parameters (factors) for 3 levels of full factorial design will refer to the Table 2.7 in Chapter 2 Literature Review. In this case, there will be 9 number of experiments in total according to the 3^2 full factorial design provided with 2 factors (parameters) at 3 levels. In this case, the fan speed (rpm) is kept constant throughout the experiment at 15,000 rpm which is at its maximum level. Whereas for the type of nozzle design and type of insulation, both of these parameters are defined by three types of designs which are the Design A, Design B and Design C. For the type of nozzle design, the Design A, Design B and Design C indicate for chrome nozzle, concentrator nozzle and diffuser nozzle, respectively. As for the type of insulation, Design A, Design B and Design C indicate for egg carton, wedge and pyramid, respectively.

The value of the respective parameters is retrieved from the Table 2.7 in Chapter 2 Literature Review and then input into the Design Expert software to generate the experimental layout plan. The experimental layout plan includes the design layout, column info sheet and also the design summary. Note that the response will only be validated through actual experiment in PSM 2 next semester. The Table 3.2 below shows the value of input parameters or also known as factors which are the type of nozzle design and type of insulation.

Table 3.2: Input parameters of the full factorial design

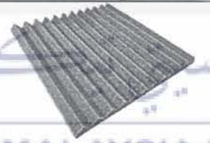
	LEVEL 1	LEVEL 2	LEVEL 3
INPUT PARAMETER 1 : TYPE OF NOZZLE DESIGN			
DESIGN	A	B	C
NUMERICAL VALUE	0.00	1.00	2.00
NAME OF NOZZLE	Chrome Nozzle	Concentrator Nozzle	Diffuser Nozzle
IMAGES			
INPUT PARAMETER 2 : TYPE OF INSULATION			
DESIGN	A	B	C
NUMERICAL VALUE	0.00	1.00	2.00
SHAPE	Egg Carton	Wedge	Pyramid
IMAGES			

Table 3.3 below shows the design layout of the full factorial design for this project. Aforementioned, there are total of three input parameters which also indicating the factors to be considered in the full factorial design of the DoE. As demonstrated by the Design Expert software, there are total of 9 runs of experiments since there are two factors set at three levels which gives a 3^2 full factorial design. The first column from the left shows the Std which stands for Standard Order that has been randomised according to the randomised factors. All two input parameters are labelled as Factor 1 and Factor 2 which indicate the type of nozzle design and the type of insulation, respectively. Whereas for the output, there are three responses altogether which are the Response 1 for air velocity (MPH), Response 2 for noise level (dB) and Response 3 for drying time (s). The responses will be obtained during the data collection in the PSM 2 for the next semester.

Table 3.3: Design layout

Std	Run	Block	Factor 1 A: Type of Nozzle Design	Factor 2 B: Type of Insulation	Response 1 Air Velocity (MPH)	Response 2 Noise Level (dB)	Response 3 Drying Time (s)
2	1	Block 1	Concentrator Nozzle	Egg Carton			
3	2	Block 1	Diffuser Nozzle	Egg Carton			
6	3	Block 1	Diffuser Nozzle	Wedge			
4	4	Block 1	Chrome Nozzle	Wedge			
7	5	Block 1	Chrome Nozzle	Pyramid			
8	6	Block 1	Concentrator Nozzle	Pyramid			
9	7	Block 1	Diffuser Nozzle	Pyramid			
5	8	Block 1	Concentrator Nozzle	Wedge			
1	9	Block 1	Chrome Nozzle	Egg Carton			

3.6 Experimental Tools and Apparatus

Figure 3.6: Hand dryer

The Figure 3.6 above shows the hand dryer that is used as the main device to be tested and run for experiments to evaluate the effect of hand dryer fan parameter on noise and aerodynamic level. The specification of the hand dryer is as following:

1) Driver input voltage/output: AC220V / DC310V
2) Motor noise: ≤65dB
3) No-load speed: 15000 ± 10% RPM
4) Torque:0.4 N.m
5) Phase number: 3 Phase
6) Motor pole: 4 Poles (2 pairs)
7) No Holzer sensor
8) Protection level: IP00
9) Working lifetime: ≥8000 h

Figure 3.7: Air flow anemometer

The Figure 3.7 above shows the air flow anemometer. The air flow anemometer is used to measure the wind speed and wind pressure of the hand dryer which gives output response in terms of the air velocity in the unit of Miles per Hour (MPH).

Figure 3.8: Sound meter

The Figure 3.8 above shows the sound meter. This sound meter is a software application of the smart phone that can be used to measure the sound levels in a standardized way. Besides, the sound meter can also respond to sound approximately similar to the human ear and provides objective, reproducible measurements of sound pressure levels.

Figure 3.9: Stopwatch

The Figure 3.9 above shows a stopwatch. This stopwatch is a software application of the smartphone which is used to measure and record the drying time of the hand dryer based on the Design of Experiment (DoE).

3.7 Experimental Set Up

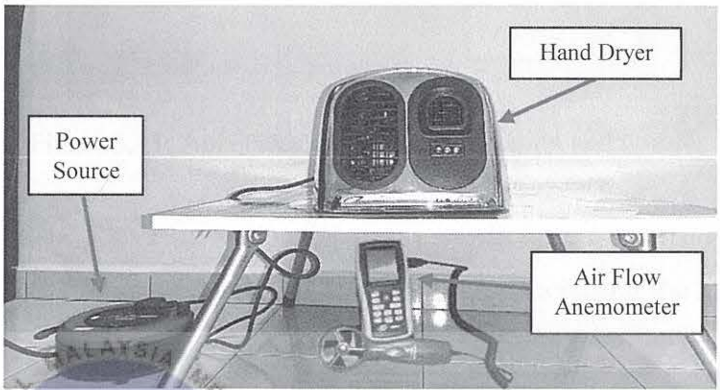


Figure 3.10: Apparatus set-up without insulation and nozzle

The Figure 3.10 above shows the apparatus set-up without insulation and nozzle. The apparatus involved in this experiment are including the hand dryer, air flow anemometer, sound meter (Android software) and the stopwatch (Android software). The aim of this experiment is to investigate the actual state of the hand dryer in terms of the air velocity, noise level, and drying time, without including any additional external factors such as the insulation and nozzle. The air velocity is measured by using the air flow anemometer. While the noise level is measured by using the sound meter which is an Android software downloaded in the smartphone. As for the drying time, the device that is used to measure the drying time is the stopwatch which is also an android software that can be found in the smartphone. All three devices were placed at a distance of 20 cm from the air outlet during the experiment.

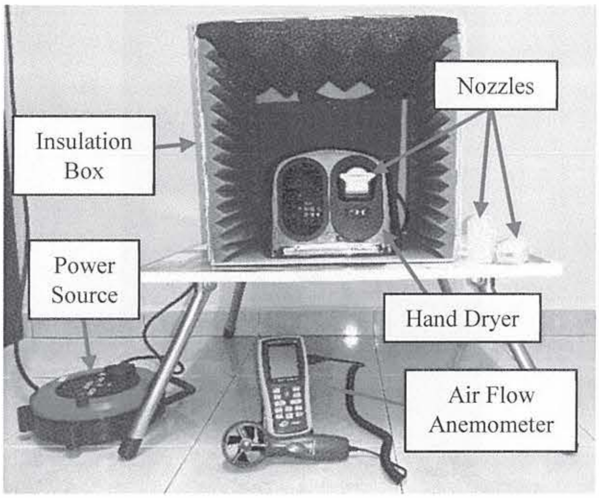


Figure 3.11: Apparatus set-up with insulation and nozzle

The Figure 3.11 above shows the apparatus set-up for the experiment with insulation and nozzle. The apparatus involved in this experiment are including the hand dryer, air flow anemometer, sound meter (Android software) and the stopwatch (Android software), nozzles, insulation foams/egg carton (for internal insulation) and insulation box. The aim of this experiment is to investigate the actual state of the hand dryer in terms of the air velocity, noise level, and drying time, with additional external factors such as the insulation and nozzle.

Similar to the previous experiment, the air velocity is measured by using the air flow anemometer. While the noise level is measured by using the sound meter which is an Android software downloaded in the smartphone. As for the drying time, the device that is used to measure the drying time is the stopwatch which is also an android software that can be found in the smartphone. All three devices were placed at a distance of 15 cm from the air outlet during the experiment.

The total number of experiments conducted was 9 times in which all three different type of nozzles which are the chrome nozzle, concentrator nozzle and diffuser nozzle were installed at the air outlet and tested accordingly to different set ups of the internal insulation of the hand dryer. The internal insulation of the hand dryer was replaced one after another experimental trials by using the egg carton, wedge foam and pyramid foam.

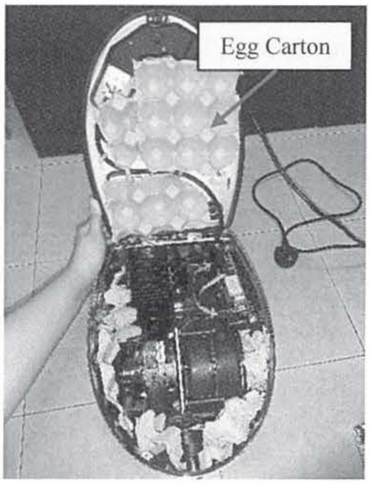


Figure 3.12: Egg carton installed in the internal motor housing and cover of hand dryer

The Figure 3.12 above shows the installation of egg carton as an insulation barrier in the internal motor housing and the cover of hand dryer. The egg carton was attached to the wall of the internal motor housing by using double sided tape to secure in place. After that, the experiment with this set up was carried out three times with different type of nozzles being inserted into the air outlet.

Figure 3.13: Wedge foam installed in the internal motor housing and cover of hand dryer

The Figure 3.13 above shows the installation of wedge foam as an insulation barrier in the internal motor housing and the cover of hand dryer. The wedge foam was attached to the wall of the internal motor housing by using double sided tape to secure in place. After that, the experiment with this set up was carried out three times with different type of nozzles being inserted into the air outlet.

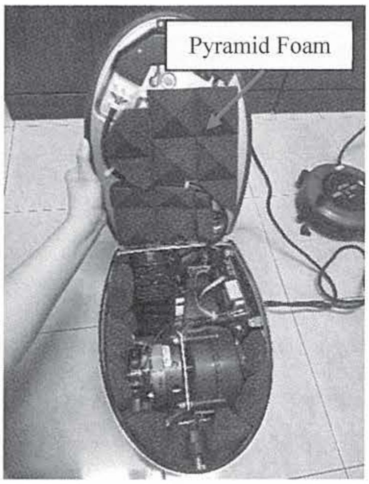


Figure 3.14: Pyramid foam installed in the internal motor housing and cover of hand dryer

The Figure 3.14 above shows the installation of pyramid foam as an insulation barrier in the internal motor housing and the cover of hand dryer. The pyramid foam was attached to the wall of the internal motor housing by using double sided tape to secure in place. After that, the experiment with this set up was carried out three times with different type of nozzles being inserted into the air outlet.

Figure 3.15: Distance marking of 15 cm from the air outlet by using yellow tape

The Figure 3.15 above shows the distance marking of 15 cm from the air outlet of the hand dryer by using a yellow tape. The figure shows wet hand being placed at the exact position of the yellow tape that was being marked with a distance of 15 cm from the air outlet during the measurement of drying time. Simultaneously, the stopwatch will be activated once the hand dryer was switched on and gives out air from the outlet.

3.8 Summary

In summary, the method of approach of the Design of Experiment (DoE) used in this project is the Full Factorial design which is by implementing the 3^2 design. The 3^2 Full Factorial design comprises of 2 factors (input parameters) to be considered in this project with each factors having 3 levels, respectively. In this case, the total number of experiment runs will be 9 runs by considering all 3 levels of input factors. The input parameters of the project is being identified are including the type of nozzle design and type of insulation. The DoE is conducted by using the Design Expert software by adjusting the settings and insert the values of input parameters and the levels.

The response of the experiment to be determined are including the air velocity (MPH), noise level in the unit of (dB) and the drying time in the unit of (s). The main device to be experimented and tested is the hand dryer which will be accommodated with various pairs of matches of the input parameters which include the type of nozzle design and the type of insulation. The type of nozzle design to be used in the DoE include the chrome nozzle, concentrator nozzle and diffuser nozzle. Whereas for the type of insulation comprised of the egg carton, wedge foam and pyramid foam. While the device apparatus used to measure the input parameters are the air flow anemometer, sound meter and stopwatch.

CHAPTER 4
RESULT AND DISCUSSION

4.0 Overview

In this Chapter 4 Result and Discussion, students are required to compile all the results obtained from the experiment and discuss the outcomes of every results with specific explanations. The results of the Design of Experiment (DoE) can be divided into three main sections which are the design, analysis and optimization. Further explanation for every sections will be included in details in the following subtopics.

4.1 Data Collection

Table 4.1 below shows the data collected from the experiment. There are two input parameters, known as Factor 1 and Factor 2 which represent the type of nozzle design and the type of insulation, respectively. While the responses from the combination of the input parameters are including the air velocity, noise level and drying time, provided with the condition that the fan speed of the hand dryer motor was kept constant at 15,000 rpm. As demonstrated by the Design Expert software, there are total of 9 run of experiments since there are two factors set at three levels which gives a 3^2 full factorial design. Since the graphical optimization requires at least two input parameters to be numerical in order to generate the result, thus, both of the input parameters were set in numerical digits as in terms of 0.00, 1.00 and 2.00 which represent the concentrator nozzle, diffuser nozzle and chrome nozzle for the type of nozzle design respectively. While for the type of insulation, the numerical digits 0.00, 1.00 and 2.00 are representing the egg carton, wedge foam and pyramid foam, respectively.

Table 4.1: Data collection

Run	Factor 1 A: Type of Nozzle Design	Factor 2 B: Type of Insulation	Response 1 Air Velocity (MPH)	Response 2 Noise Level (dB)	Response 3 Drying Time (s)
1	Concentrator Nozzle (1.00)	Egg Carton (0.00)	27.86	81	14.53
2	Diffuser Nozzle (2.00)	Egg Carton (0.00)	21.18	82	18.38
3	Diffuser Nozzle (2.00)	Wedge Foam (1.00)	32.83	81	18.4
4	Chrome Nozzle (0.00)	Wedge Foam (1.00)	46.07	76	10.75
5	Chrome Nozzle (0.00)	Pyramid Foam (2.00)	38.63	77	10.43
6	Concentrator Nozzle (1.00)	Pyramid Foam (2.00)	31.54	79	14.24
7	Diffuser Nozzle (2.00)	Pyramid Foam (2.00)	31.37	81	18.6
8	Concentrator Nozzle (1.00)	Wedge Foam (1.00)	37.73	79	15.03
9	Chrome Nozzle (0.00)	Egg Carton (0.00)	45.52	79	11.83

Generated by: Design Expert software

The Table 4.2 below shows the column info sheet of the full factorial design. Basically, the column info sheet represents all the necessary information such as the units, type, standard deviation, low and high range which are corresponding to the all the factors and the responses respectively. From the table, the standard deviation for the factors are 0. While for the responses, the air velocity has a higher standard deviation compared to the other two responses which indicates the data will have greater variability in the test scores. The low and high range for the type of nozzle design and type of insulation are set as 0 and 2 respectively. In actual, 0 indicates concentrator nozzle and egg carton, while 2 indicates chrome nozzle and pyramid foam for the type of nozzle design and type of insulation, respectively.

Table 4.2: Column info sheet

Name	Units	Type	Std.Dev.	Low	High
Type of Nozzle Design	-	Factor	0	0	2
Type of Insulation	-	Factor	0	0	2
Air Velocity	MPH	Response	1.52003	21.18	46.07
Noise Level	dB	Response	0.822147	76	82
Drying Time	s	Response	0.297889	10.43	18.6

Generated by: Design Expert software

4.2 Status of Design

The Table 4.3 below shows the design summary of the full factorial design. The design summary shows that the type of study is factorial design in which the initial design is in terms of full factorial. While the design model is a reduced linear. The total number of experiments is 9 which also gives a total number of 9 observations (Obs). There are three responses which indicated by Y1, Y2 and Y3 for the air velocity in the units of MPH, noise level in the units of dB and drying time in the units of seconds (s). From the data collection obtained during the experiment, it can be summarised that the minimum air velocity is 21.18 MPH while the maximum air velocity is 46.07 MPH. As for the noise level, the minimum limit is at 76.00 dB while the maximum limit is at 82.00 dB. Whereas for the drying time, the minimum limit is at 10.43 s, while the maximum limit is at 18.60 s.

Based on the data collected, suitable models are assigned to each responses for their respective analysis which are suggested by the Design Expert software. In this case, the suitable model suggested for the 1st response Y1 which is the air velocity is the quadratic model. While the suitable model suggested for the 2nd response Y2 which is the noise level is the linear model. As for the 3rd response Y3 which is the drying time, the suitable model suggested is the two-factor interaction (2FI) model. As for factor A which indicate the type of nozzle design, the factor is set at 3 levels in which the low actual is 0.000 indicating the chrome nozzle, while the high actual is 2.00 indicating the diffuser nozzle. While for factor B which indicate the type of insulation, the factor is also set at 3 levels in which the low actual is 0.000 indicating the egg carton while the high actual is 2.00 indicating the pyramid foam.

Table 4.3: Design summary

Design Summary							
Study Type	Factorial		**Experiments**	9			
Initial Design	Full Factorial		**Blocks**	0			
Design Model	2FI						
Response	**Name**	**Units**	**Obs**	**Minimum**	**Maximum**	**Trans**	**Model**
Y1	Air Velocity	MPH	9	21.18	46.07	None	Quadratic
Y2	Noise Level	dB	9	76.00	82.00	None	Linear
Y3	Drying Time	s	9	10.43	18.6	None	2FI
Factor	**Name**	**Units**	**Type**	**Low Actual**	**High Actual**	**Low Coded**	**High Coded**
A	Type of Nozzle Design		Numeric	0.000	2.00	-1.000	1.000
B	Type of Insulation		Numeric	0.000	2.00	-1.000	1.000

4.3 Evaluation of Design

The following Figure 4.1 shows the standard error plot between the type of insulation and the type of nozzle design. Based on the graph, there are 2 factors A and B which representing the x-axis and y-axis respectively. There are 9 red circles on the graph which indicate different design points based on the 9 run of experiments. The intercept of the graph falls on the x-axis at value 1.00 of the factor A, which indicates the concentrator nozzle in actual. According to the result generated by the Design Expert software, there are no aliases found for the Reduced Linear Model. The basis standard deviation is equivalent to 1.0 while the average value for the leverage of 9 design points is 0.2222. The suggested model is polynomial with modified order.

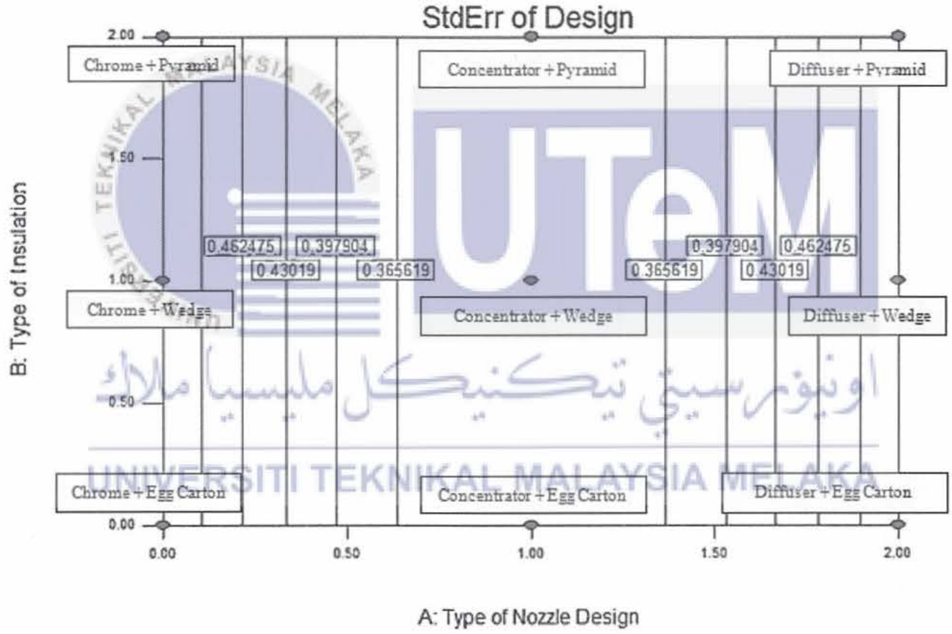


Figure 4.1: Standard Error Plot

4.4 Analysis of Air Velocity

In order to achieve the second objective of this project which is to analyse the correlation between the input parameters and the response, the data will be analysed. In this case, the Analysis of Variance (ANOVA) is used to determine the effect of significant input parameters which are the type of nozzle design and the type of insulation towards the air velocity as the first response.

4.4.1 Fit Summary

The fit summary of the model calculates the regression to fit all of the polynomial models to the selected response. Several useful statistical tables are generated to determine the suitable model. Table 4.4 below shows the sequential model sum of square whereby different source of models are compared by showing the improvement in model fit as terms are added. The highest order of polynomial should be selected for sequential model sum of square where the additional terms are significant and the model is not aliased. In this case, the quadratic model is suggested by the software and has been selected since it has the highest order of polynomial in terms of the Prob > F which is 0.0160.

Table 4.4: Sequential model sum of squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	10866.67	1	10866.67			
Linear	343.22	2	171.61	5.66	0.0416	
2FI	72.93	1	72.93	3.35	0.1268	
Quadratic	102.01	2	51.01	22.08	0.0160	Suggested
Cubic	3.56	2	1.78	0.53	0.6976	Aliased
Residual	3.37	1	3.37			
Total	11391.77	9	1265.75			

Table 4.5 below shows the model summary statistics. The standard deviation estimates the error in the design, the R-squared represents the variation while the PRESS measures how the model fits each point in the design. Ideally, the model with low standard deviation, R-squared near to the value of 1 is the best combination provided that it has a relatively low PRESS. The selection should focus on the model that maximizing Adjusted R-squared and Predicted R-squared. In this case, the quadratic model was suggested by the software.

Table 4.5: Model summary statistics

Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	5.51	0.6536	0.5382	0.1570	442.68	
2FI	4.67	0.7925	0.6680	0.5714	225.04	
Quadratic	1.52	0.9868	0.9648	0.8696	68.47	Suggested
Cubic	1.84	0.9936	0.9486	-0.1708	614.79	Aliased

4.4.2 ANOVA

In order to specify the influence of input parameters on the air velocity, Analysis of Variance (ANOVA) method is used. Quadratic model is suggested for the air velocity with Prob > F of 0.0051 and model F-value of 44.85 which implies the model is significant as shown in Table 4.6 below. There is only a 0.51% chance that a "Model F-Value" this large could occur due to noise. The value of Prob > F which is less than 0.0500 indicates the model terms are significant. In this case, the type of nozzle design (A), interaction between different type of nozzle designs (A^2), interaction between different type of insulations (B^2), and the interaction between different type of nozzle design and insulation (AB) are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. In this case, the type of insulation (B) is not a significant model as it has a Prob > F value of 0.1575. If there are many insignificant model terms not counting those required to support hierarchy, model reduction may improve the selected model.

Table 4.6: ANOVA table for air velocity

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	518.17	5	103.63	44.85	0.0051	significant
A	335.10	1	335.10	145.04	0.0012	
B	8.12	1	8.12	3.51	0.1575	
A^2	25.30	1	25.3	10.95	0.0454	
B^2	76.71	1	76.71	33.20	0.0104	
AB	72.93	1	72.93	31.57	0.0111	
Residual	6.93	3	2.31			
Cor Total	525.10	8				

4.4.3 Regression Statistic

In Table 4.5 below, the value Pred R-squared of 0.8696 shows that it is in a reasonable agreement with the value Adj R-squared of 0.9648. The R-squared shows a value of 0.9868 which is very near to 1.000 indicates that it is desirable. The Adeq. Precision value measures the signal to noise ratio. With a ratio greater than 4, it is desirable and the ratio shown is 21.411 indicating an adequate signal. Hence, this model can be used to navigate the design space.

Table 4.7: Regression statistic

Std. Dev.	1.52	R-Squared	0.9868
Mean	34.75	Adj R-Squared	0.9648
C.V.	4.37	Pred R-Squared	0.8696
PRESS	68.47	Adeq Precision	21.411

4.4.4 Final Equations

Table 4.8 below shows the table to generate the final equation in terms of the coded factors. The final equation in terms of coded factors is generated by considering the coefficient estimate along with the factor. During the generation of equation, plus '+' and minus '-' signs of the coefficient estimate must be considered throughout the equation and are multiplied to each of the corresponding factors.

Table 4.8: Table to generate final equation in terms of coded factors

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	36.51	1	1.13	32.9	40.11	
A-Type of Nozzle Design	-7.47	1	0.62	-9.45	-5.5	1
B-Type of Insulation	1.16	1	0.62	-0.81	3.14	1
A2	3.56	1	1.07	0.14	6.98	1
B2	-6.19	1	1.07	-9.61	-2.77	1
AB	4.27	1	0.76	1.85	6.69	1

The final equation in terms of coded factors:

Air Velocity = + 36.51 - 7.47 (A) + 1.16 (B) + 3.56 (A^2) - 6.19 (B^2) + 4.27 (AB) Equation 4.1

The final equation in terms of actual factors:

Air Velocity = + 44.44889 - 18.85667 (Type of Nozzle Design) + 9.28 (Type of Insulation) + 3.55667 (Type of Nozzle Design^2) - 6.19333 (Type of Insulation^2) + 4.27 (Type of Nozzle Design * Type of Insulation) Equation 4.2

4.4.5 Diagnostics Case Statistics

Table 4.9 below shows the diagnostics case statistics. The diagnostics case statistics is a compilation of data to be used for regression analysis in order to seek for assessment in the validity of a model in any number with different ways. In this case, the diagnostics case statistics contain data for various types of diagnostics graphs such as the normal probability plot, residual vs. predicted plot, residual vs. run plot, residual vs. factor plot, outlier T plot, Cook's distance plot, leverage plot, predicted vs. actual plot and lastly the Box Cox plot.

Table 4.9: Diagnostics case statistics

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	45.52	44.45	1.07	0.806	1.598	1.763	3.383	9
2	27.86	29.15	-1.29	0.556	-1.272	0.337	-1.53	1
3	21.18	20.96	0.22	0.806	0.325	0.073	0.27	2
4	46.07	47.54	-1.47	0.556	-1.446	0.436	-2.146	4
5	37.73	36.51	1.22	0.556	1.208	0.304	1.377	8
6	32.83	32.59	0.24	0.556	0.238	0.012	0.196	3
7	38.63	38.24	0.39	0.806	0.588	0.239	0.511	5
8	31.54	31.48	0.064	0.556	0.064	0.001	0.052	6
9	31.37	31.83	-0.46	0.806	-0.685	0.324	-0.609	7

4.4.6 Model Diagnostics Plots

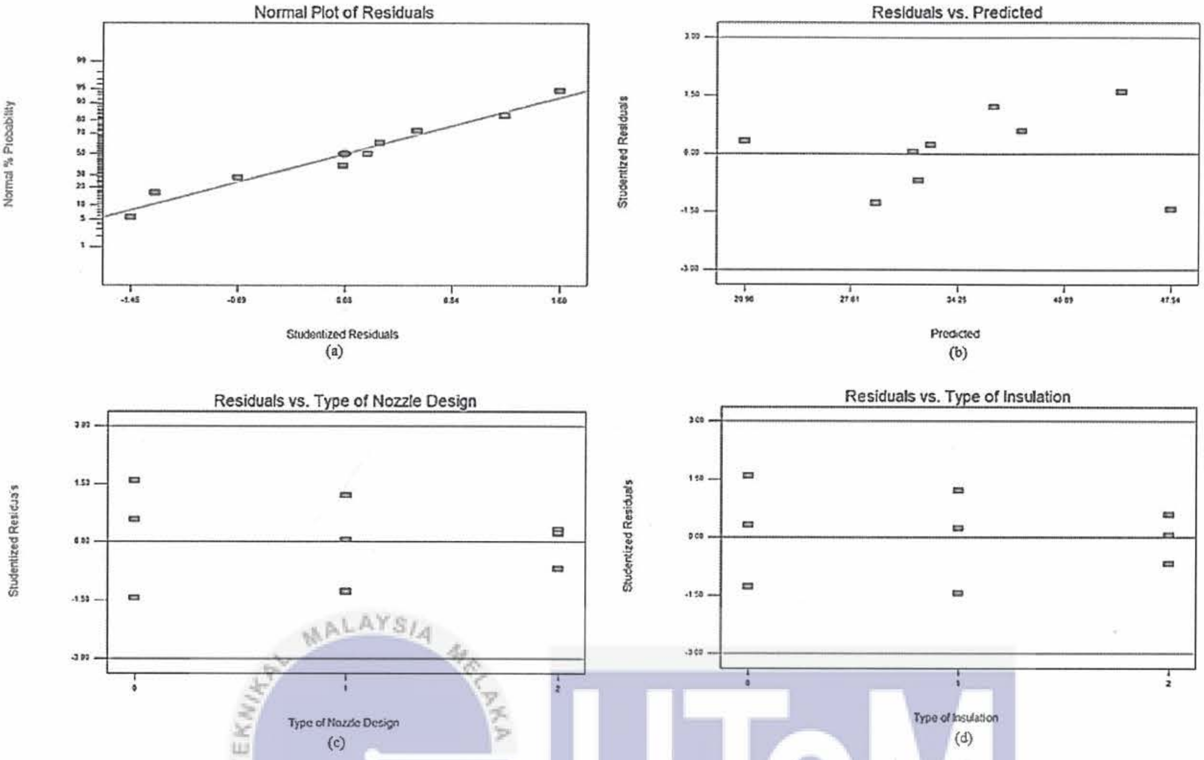


Figure 4.2: (a) Normal plot vs. residuals, (b) Residuals vs. predicted plot, (c) Residuals vs. type of nozzle design plot, (d) Residuals vs. type of insulation plot.

The model diagnostics plot shows the plot of residual on how well the models satisfy the assumption of ANOVA. The Figure 4.2 (a) above shows the normal probability plot of residual for the air velocity. It reveals that a check point on the plots that the residual generally falls on a straight line implying the errors is distributed normally. While Figure 4.2 (b), Figure 4.2 (c), and Figure 4.2 (d) shows the residual vs. the predicted plot, residuals vs. type of nozzle design plot and residual vs. type of insulation plot, respectively. From these three plots, it can be observed that there are no unusual pattern and outliers found throughout the plots.

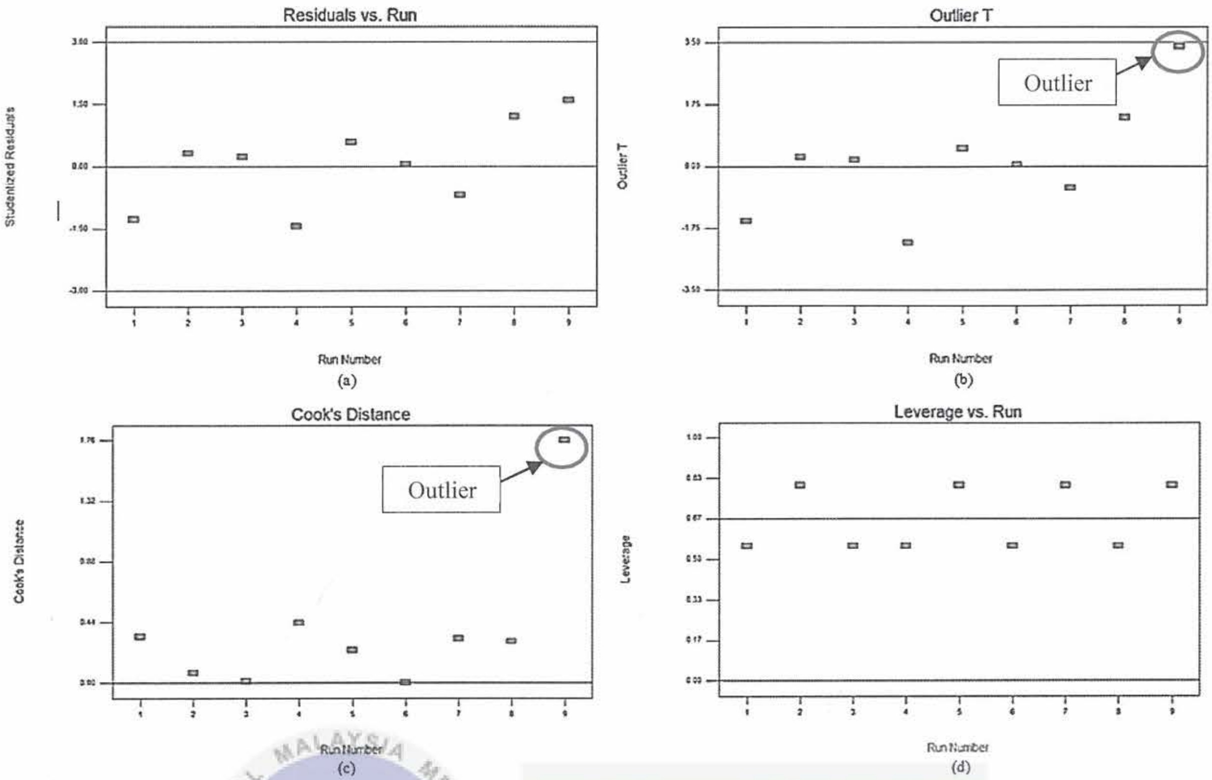
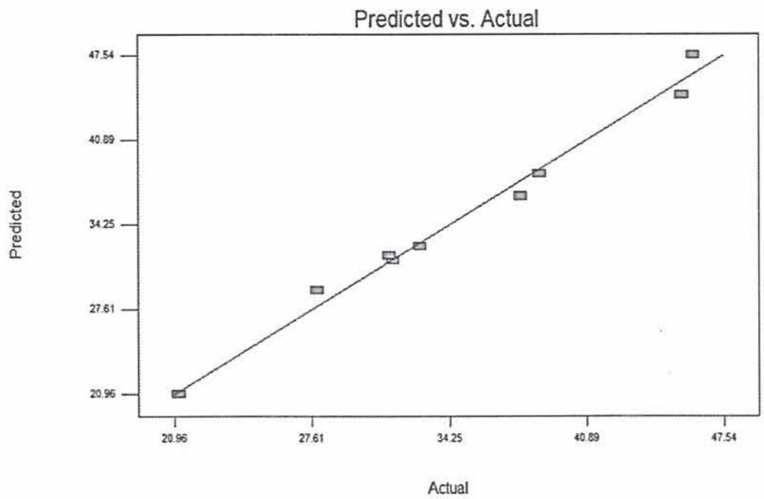
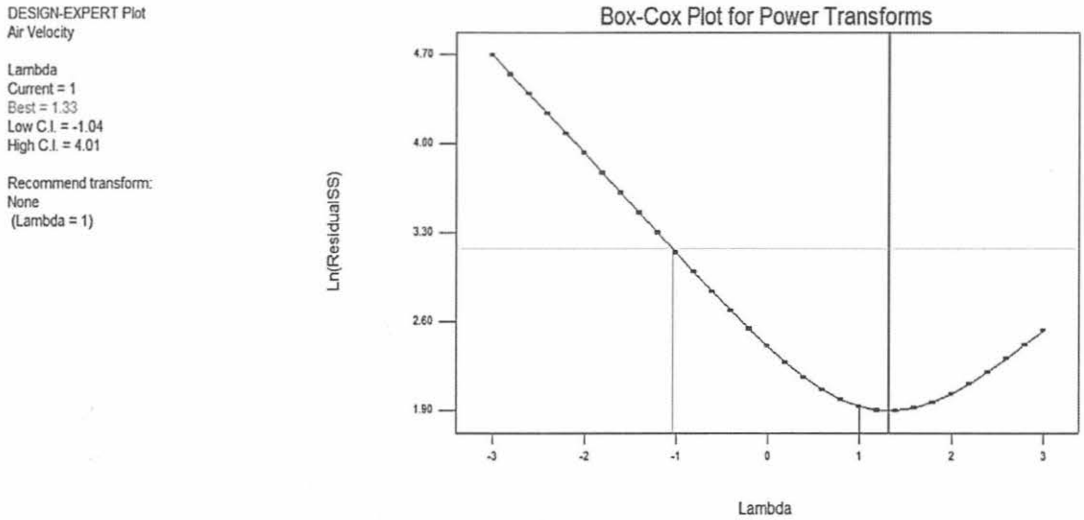


Figure 4.3: (a) Residuals vs. run plot, (b) Outlier T plot, (c) Cook's distance plot, (d) Leverage vs. run plot.

On the other hand, Figure 4.3 (a), Figure 4.3 (b), Figure 4.3 (c) and Figure 4.3 (d) above shows the residual vs. run plot, outlier T plot, Cook's distance plot and leverage vs. run plot, respectively. The residual vs. run plot shows a random scatter with no lurking variables detected. While the outlier T plot and Cook's distance plot happen to have an outlier at the same run number which is the 9th run of the design point. As for the leverage vs. run plot, the design points are consistent throughout the graph which gives a random scatter pattern.



(a)



(b)

Figure 4.4: (a) Predicted vs. actual plot, (b) Box-Cox plot for power transforms.

The above Figure 4.4 (a) shows the predicted vs. actual plot while Figure 4.4 (b) shows the Box-Cox plot for power transforms. The predicted vs. actual plot shows the effect of the model by comparing it against the null model. In this case, the points on the graph are relatively close to the fitted line with narrow confidence bands without any possible outliers being detected. Thus, the predicted vs. actual plot has a good fit. On the other hand, the Box-Cox plot for power transforms interpret that the value of Lambda is equivalent to 1. Thus, no transformation is needed. In this case, the best lambda value is 1.33 provided that both of the low and high confidence interval (C.I.) values are -1.04 and 4.01, respectively.

4.4.7 Perturbation Plot of Air Velocity

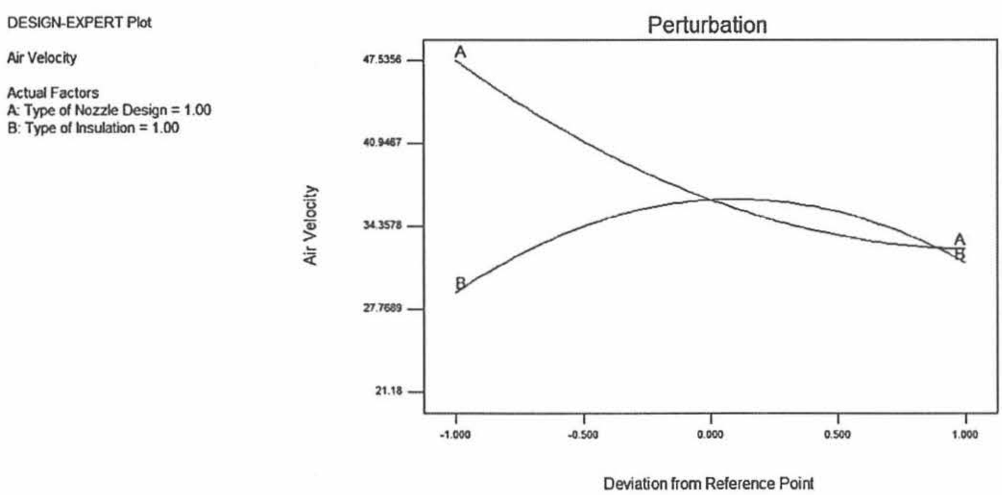


Figure 4.5: Perturbation plot of air velocity

The Figure 4.5 above shows the perturbation plot of the air velocity. In general, the perturbation plot is used to study the effect of specific factors towards the response in the design space. The relatively flat line suggests insensitivity to change in that specific factors. While the steepest curvature indicates the factor that is most significantly affects the response. Factor A and B are the type of nozzle design and type of insulation, respectively as shown in the Figure 4.5 below. Both of the Factors A and B were deviated at a distance of 1.000 from the default reference point of 0.000. In this case, the Factor A which is the type of nozzle design is considered to be the factor that can significantly affects the air velocity since it has the steepest curvature compared to the Factor B.

4.4.8 3D Surface Plot of Air Velocity

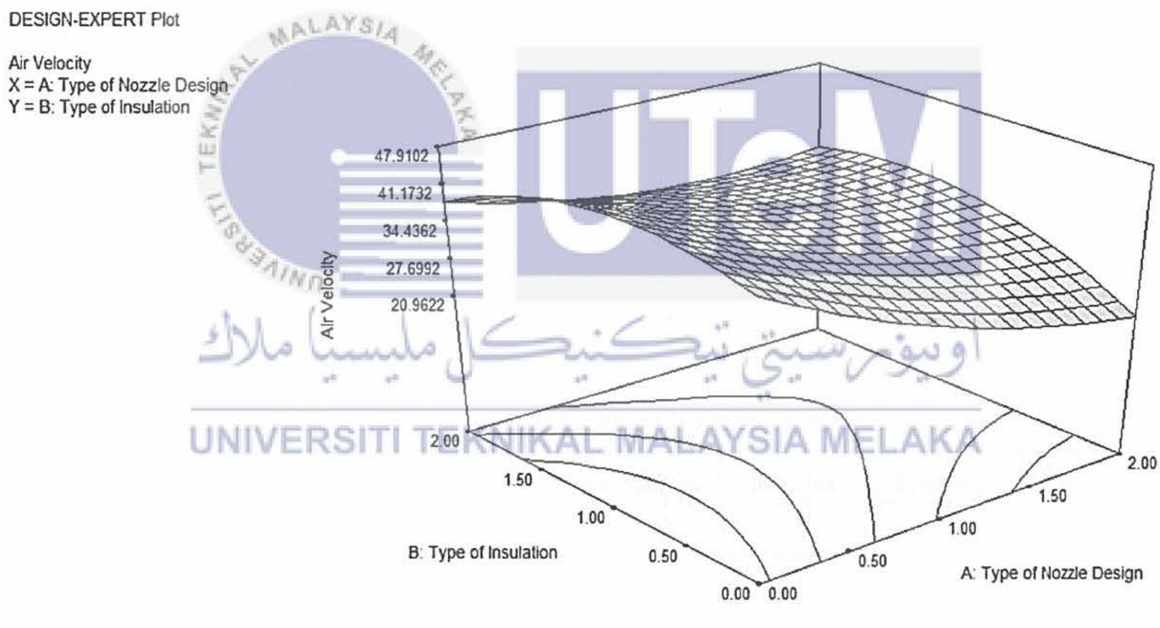


Figure 4.6: 3D surface plot of air velocity

Figure 4.6 above shows the 3D surface plot for the factor type of nozzle design and type of insulation with response to air velocity. It can be observed that the highest air velocity is obtained when the type of nozzle design is 0.00 and the type of insulation is 1.00. This also indicates that the type of nozzle design is the chrome nozzle while the type of insulation is the wedge foam. Thus, this can also be considered as the best possible combination of factors that is able to achieved the most desirable output response which is the maximum air velocity at an approximate value of 45.7975 MPH according to the Solution 1 suggested in Table 4.23.

4.5 Analysis of Noise Level

In order to achieve the second objective of this project which is to analyse the correlation between the input parameters and the response, the data will be analysed. In this case, the Analysis of Variance (ANOVA) is used to determine the effect of significant input parameters which are the type of nozzle design and the type of insulation towards the noise level as the second response.

4.5.1 Fit Summary

The fit summary of the model calculates the regression to fit all of the polynomial models to the selected response. Several useful statistical tables are generated to determine the suitable model. Table 4.10 below shows the sequential model sum of square whereby different source of models are compared by showing the improvement in model fit as terms are added. The highest order of polynomial should be selected for sequential model sum of square where the additional terms are significant and the model is not aliased. In this case, the linear model has been selected since it has the highest order of polynomial in terms of the Prob > F of 0.0020.

Table 4.10: Sequential model sum of squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	56802.78	1	56802.78			
Linear	28.17	2	14.08	20.84	0.0020	Suggested
2FI	0.25	1	0.25	0.33	0.5914	
Quadratic	2.94	2	1.47	5.13	0.1076	
Cubic	0.83	2	0.42	15.00	0.1796	Aliased
Residual	0.028	1	0.028			
Total	56835	9	6315.00			

Table 4.11 below shows the model summary statistics. The standard deviation estimates the error in the design, the R-squared represents the variation while the PRESS measures how the model fits each point in the design. Ideally, the model with low standard deviation, R-squared near to the value of 1 is the best combination provided that it has a

relatively low PRESS. The selection should focus on the model that maximizing Adjusted R-squared and Predicted R-squared. In this case, the linear model was suggested by the software.

Table 4.11 Model summary statistics

Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.82	0.8741	0.8322	0.7257	8.84	Suggested
2FI	0.87	0.8819	0.8110	0.5998	12.89	
Quadratic	0.54	0.9733	0.9287	0.6783	10.37	
Cubic	0.17	0.9991	0.9931	0.8429	5.06	Aliased

4.5.2 ANOVA

In order to specify the influence of input parameters on the noise level, Analysis of Variance (ANOVA) method is used. Linear model is suggested for the noise level with Prob > F of 0.0020 and model F-value of 20.84 which implies the model is significant as shown in Table 4.12 below. There is only a 0.20% chance that a "Model F-Value" this large could occur due to noise. The value of Prob > F which is less than 0.0500 indicates the model terms are significant. In this case, the type of nozzle design (A) and the type of insulation (B) is a significant model as it has a Prob > F value of 0.0010 and 0.0476, respectively. If there are many insignificant model terms not counting those required to support hierarchy, model reduction may improve the selected model.

Table 4.12: ANOVA table for noise level

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	28.17	2	14.08	20.84	0.0020	significant
A	24.00	1	24.00	35.51	0.0010	
B	4.17	1	4.17	6.16	0.0476	
Residual	4.06	6	0.68			
Cor Total	32.22	8				

4.5.3 Regression Statistic

In Table 4.13 below, the value Pred R-squared of 0.7257 indicating a reasonable agreement with the value Adj R-squared of 0.8322. The R-squared shows a value of 0.8741 which is very near to 1.000 is considered desirable. The Adeq. Precision value measures the signal to noise ratio. With a ratio greater than 4, it is desirable and the ratio shown is 11.938 indicating an adequate signal. Hence, this model can be used to navigate the design space.

Table 4.13: Regression statistic

Std. Dev.	0.82	R-Squared	0.8741
Mean	79.44	Adj R-Squared	0.8322
C.V.	1.03	Pred R-Squared	0.7257
PRESS	8.84	Adeq Precision	11.938

4.5.4 Final Equations

Table 4.14 below shows the table to generate the final equation in terms of the coded factors. The final equation in terms of coded factors is generated by considering the coefficient estimate along with the factor. During the generation of equation, plus '+' and minus '-' signs of the coefficient estimate must be considered throughout the equation and are multiplied to each of the corresponding factors.

Table 4.14: Table to generate final equation in terms of coded factors

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	79.44	1	0.27	78.77	80.12	
A-Type of Nozzle Design	2.00	1	0.34	1.18	2.82	1
B-Type of Insulation	-0.83	1	0.34	-1.65	-0.012	1

Final Equation in Terms of Coded Factors:

Noise Level = + 79.44 + 2.00 (A) - 0.83 (B) Equation 4.3

Final Equation in Terms of Coded Factors:

Noise Level = + 78.27778 + 2.00000 (Type of Nozzle Design) - 0.83333 (Type of Insulation) Equation 4.4

4.5.5 Diagnostics Case Statistics

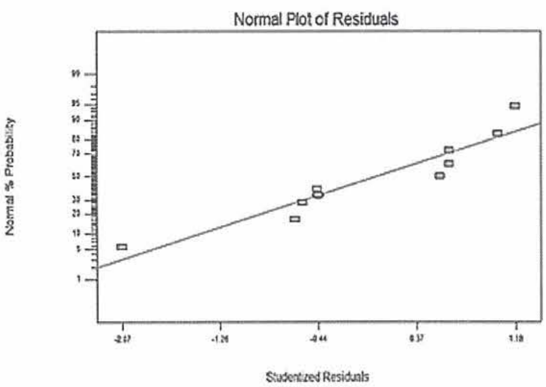
Table 4.15 below shows the diagnostics case statistics. The diagnostics case statistics is a compilation of data to be used for regression analysis in order to seek for assessment in the validity of a model in any number with different ways. In this case, the diagnostics case statistics contain data for various types of diagnostics graphs such as the normal probability plot, residual vs. predicted plot, residual vs. run plot, residual vs. factor plot, outlier T plot, Cook's distance plot, leverage plot, predicted vs. actual plot and lastly the Box Cox plot.

Table 4.15: Diagnostics case statistics

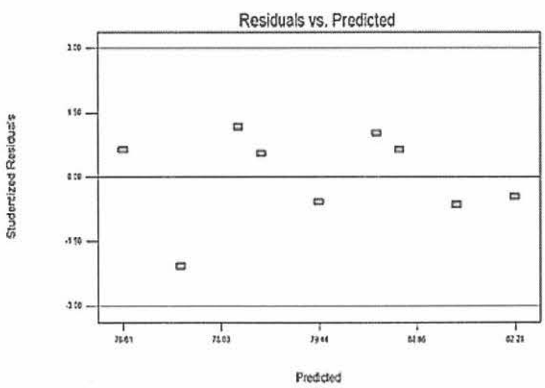
Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	79.00	78.28	0.72	0.444	1.179	0.370	1.227	9
2	81.00	80.28	0.72	0.278	1.034	0.137	1.041	1
3	82.00	82.28	-0.28	0.444	-0.453	0.055	-0.421	2
4	76.00	77.44	-1.44	0.278	-2.067	0.548	-3.519 *	4
5	79.00	79.44	-0.44	0.111	-0.573	0.014	-0.538	8
6	81.00	81.44	-0.44	0.278	-0.636	0.052	-0.601	3
7	77.00	76.61	0.39	0.444	0.635	0.107	0.600	5
8	79.00	78.61	0.39	0.278	0.557	0.040	0.522	6
9	81.00	80.61	0.39	0.444	0.635	0.107	0.600	7

Note: Case(s) with |Outlier| > 3.50

4.5.6 Model Diagnostics Plots



(a)



(b)

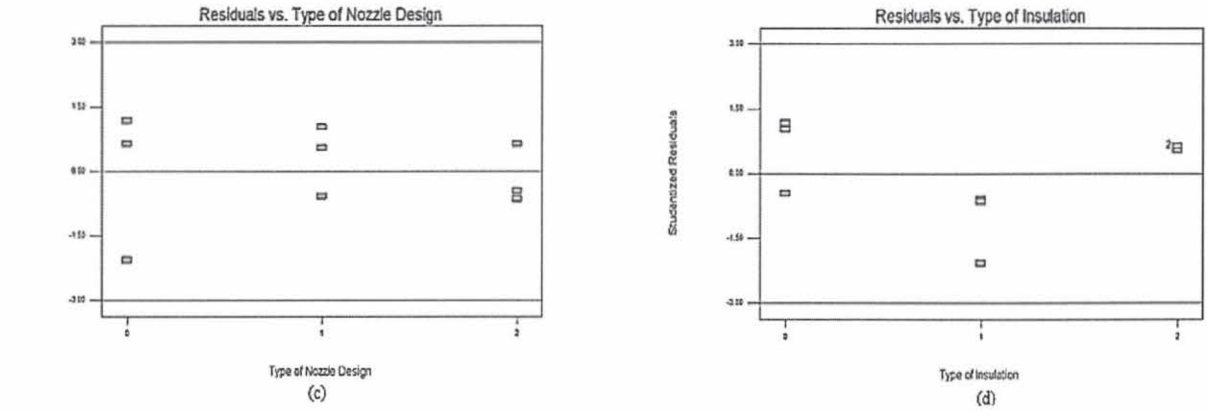


Figure 4.7: (a) Normal plot vs. residuals, (b) Residuals vs. predicted plot, (c) Residuals vs. type of nozzle design plot, (d) Residuals vs. type of insulation plot.

The model diagnostics plot shows the plot of residual on how well the models satisfy the assumption of ANOVA. The Figure 4.7 (a) above shows the normal probability plot of residual for the noise level. It reveals that a check point on the plots that the residual generally falls on a straight line implying the errors is distributed normally. While Figure 4.7 (b), Figure 4.7 (c), and Figure 4.7 (d) shows the residual vs. the predicted plot, residuals vs. type of nozzle design plot and residual vs. type of insulation plot, respectively. It can be observed that there are no unusual pattern and outliers found throughout these three plots.

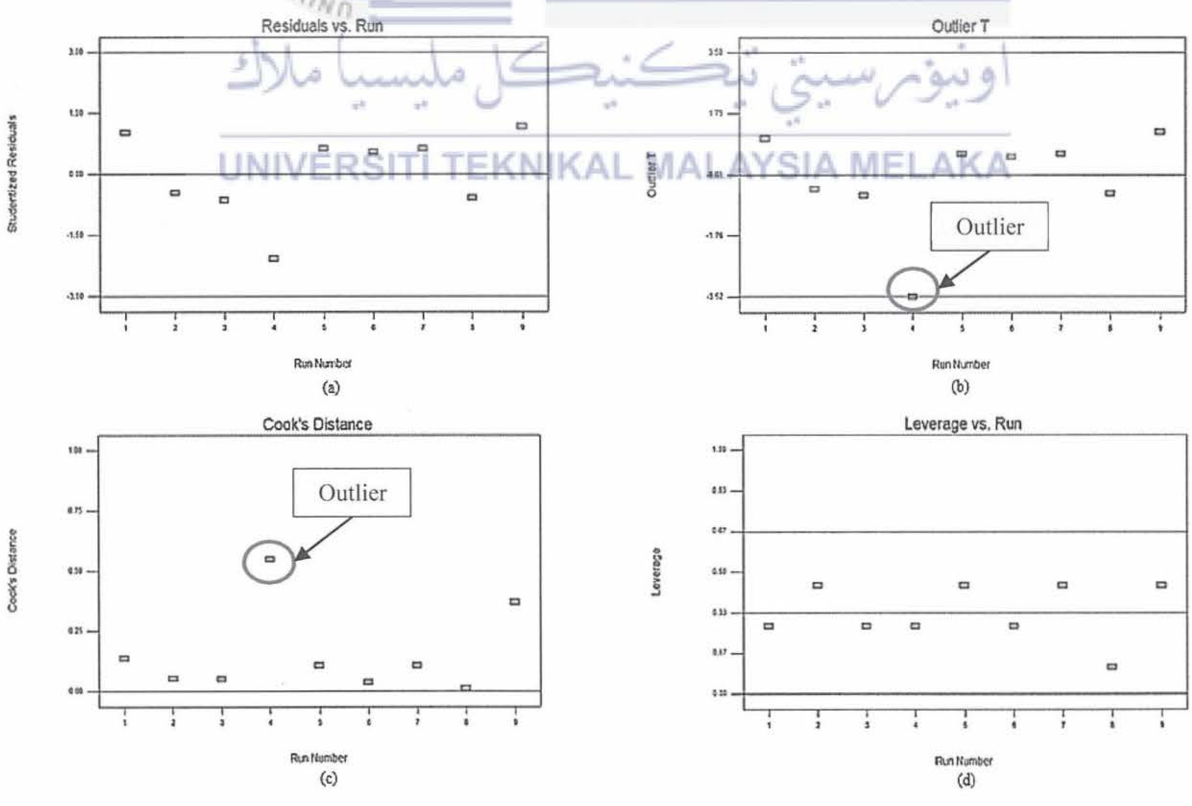
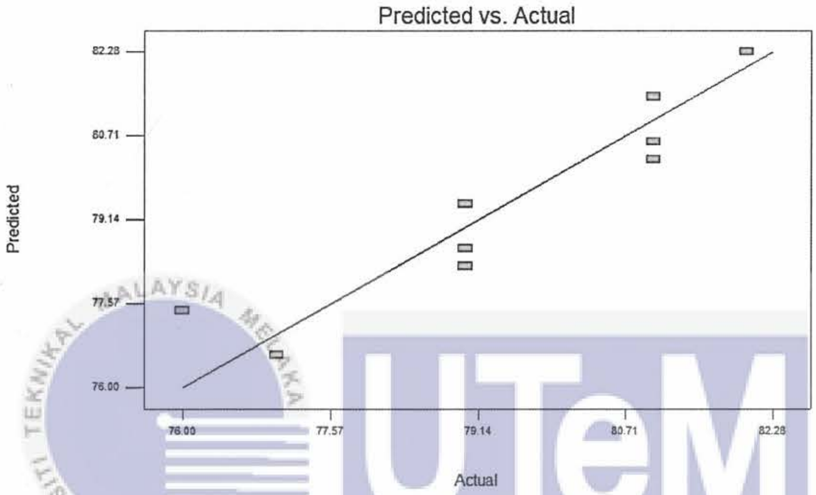
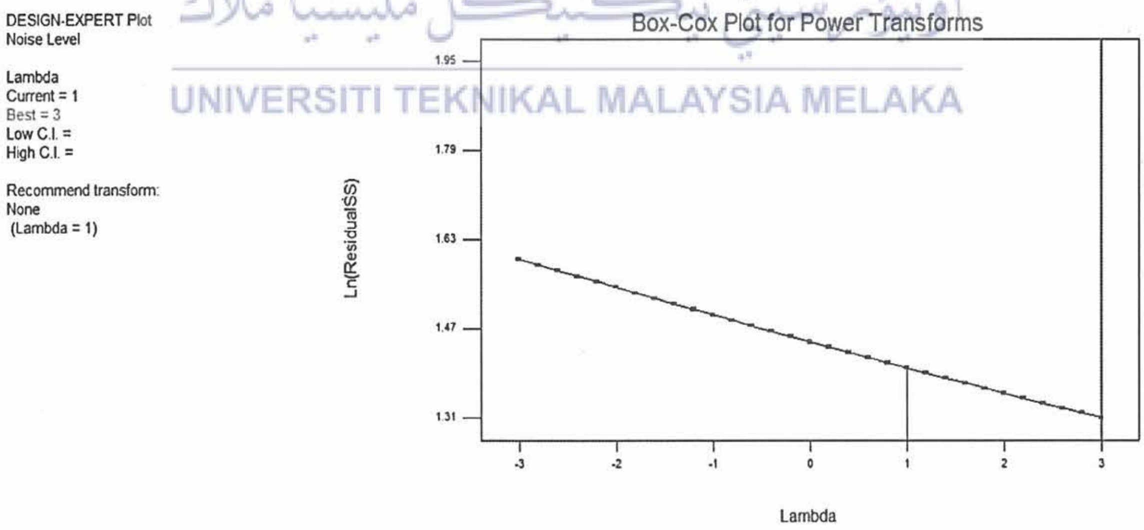


Figure 4.8: (a) Residuals vs. run plot, (b) Outlier T plot, (c) Cook's distance plot, (d) Leverage vs. run plot.

On the other hand, Figure 4.8 (a), Figure 4.8 (b), Figure 4.8 (c) and Figure 4.8 (d) above shows the residual vs. run plot, outlier T plot, Cook's distance plot and leverage vs. run plot, respectively. The residual vs. run plot shows a random scatter with no lurking variables detected. While the outlier T plot and Cook's distance plot happen to have an outlier at the same run number which is the 4th run of the design point. As for the leverage vs. run plot, the design points are consistent throughout the graph which gives a random scatter pattern.



(a)



(b)

Figure 4.9: (a) Predicted vs. actual plot, (b) Box-Cox plot for power transforms.

The above Figure 4.9 (a) shows the predicted vs. actual plot while Figure 4.9 (b) shows the Box-Cox plot for power transforms. The predicted vs. actual plot shows the effect of the model by comparing it against the null model. In this case, the points on the graph are relatively close to the fitted line with narrow confidence bands without any possible outliers being detected. Thus, the predicted vs. actual plot has a good fit. On the other hand, the Box-Cox plot for power transforms interpret that the value of Lambda is equivalent to 1. Thus, no transformation is needed. In this case, the best lambda value is 3 which is the highest value of the lambda in this plot.

4.5.7 Perturbation Plot of Noise Level

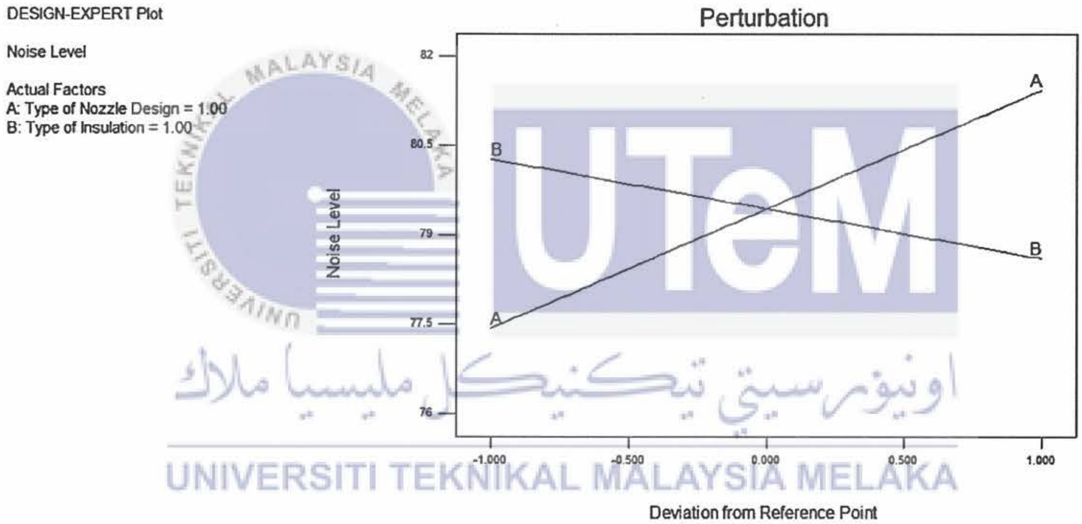


Figure 4.10: Perturbation plot of noise level

The Figure 4.10 above shows the perturbation plot of the noise level. In general, the perturbation plot is used to study the effect of specific factors towards the response in the design space. The relatively flat line suggests insensitivity to change in that specific factors. While the steepest curvature indicates the factor that is most significantly affects the response. Factor A and B are the type of nozzle design and type of insulation, respectively as shown in the Figure 4.10 above. Both of the Factors A and B were deviated at a distance of 1.000 from the default reference point of 0.000. In this case, both Factor A and Factor B can be considered as the factors that are insensitivity to change in the noise level of the hand dryer since both of these factors are relatively flat lines.

4.5.8 3D Surface Plot of Noise Level

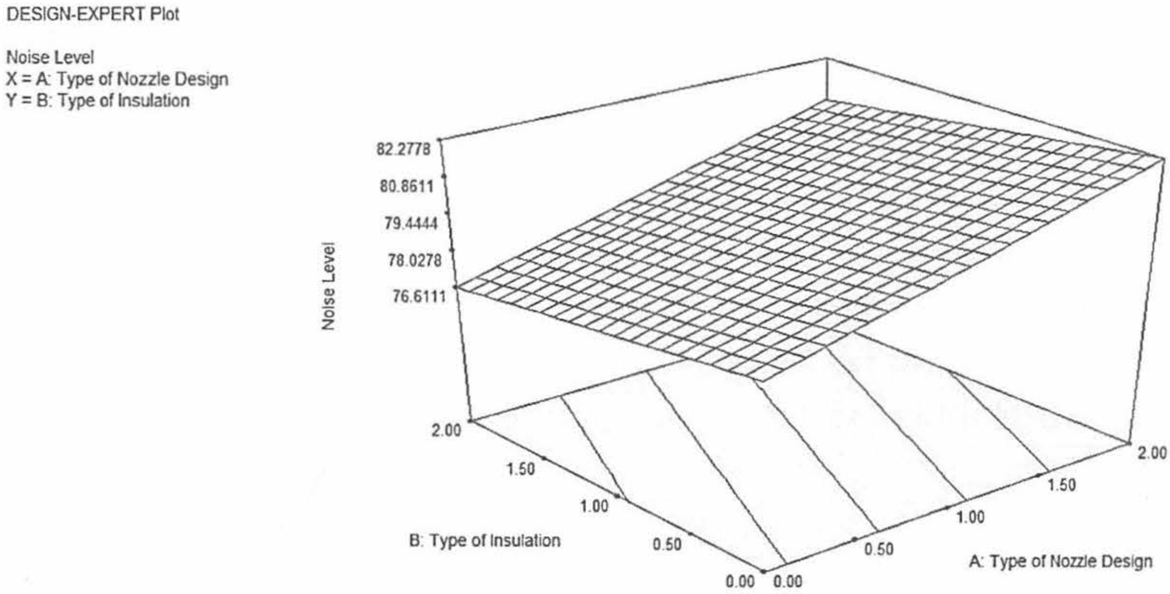


Figure 4.11: 3D surface plot of noise level

Figure 4.11 above shows the 3D surface plot for the factor type of nozzle design and type of insulation with response to noise level. It can be observed that the lowest noise level is obtained when the type of nozzle design is 0.00 and the type of insulation is 2.00. This also indicates that the type of nozzle design is the chrome nozzle while the type of insulation is the pyramid foam. Thus, this can also be considered as the best possible combination of factors that is able to achieved the most desirable output response which is the minimum noise level at an approximate value of 77.165 dB according to the Solution 1 suggested in Table 4.23.

4.6 Analysis of Drying Time

In order to achieve the second objective of this project which is to analyse the correlation between the input parameters and the response, the data will be analysed. In this case, the Analysis of Variance (ANOVA) is used to determine the effect of significant input parameters which are the type of nozzle design and the type of insulation towards the drying time as the third response.

4.6.1 Fit Summary

The fit summary of the model calculates the regression to fit all of the polynomial models to the selected response. Several useful statistical tables are generated to determine the suitable model. Table 4.16 below shows the sequential model sum of square whereby different source of models are compared by showing the improvement in model fit as terms are added. The highest order of polynomial should be selected for sequential model sum of square where the additional terms are significant and the model is not aliased. In this case, the two-factor interaction (2FI) model is suggested by the software and has been selected since it has the highest order of polynomial in terms of the Prob > F which is 0.0418.

Table 4.16: Sequential model sum of squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	1941.58	1	1941.58			
Linear	83.76	2	41.88	228.49	< 0.0001	
2FI	0.66	1	0.66	7.39	0.0418	Suggested
Quadratic	0.041	2	0.021	0.15	0.8631	
Cubic	0.058	2	0.029	0.084	0.9250	Aliased
Residual	0.34	1	0.34			
Total	2026.44	9	225.16			

Table 4.17 below shows the model summary statistics. The standard deviation estimates the error in the design, the R-squared represents the variation while the PRESS measures how the model fits each point in the design. Ideally, the model with low standard deviation, R-squared near to the value of 1 is the best combination provided that it has a relatively low PRESS. The selection should focus on the model that maximizing Adjusted R-squared and Predicted R-squared. In this case, the two-factor interaction (2FI) model was suggested by the software.

Table 4.17: Model summary statistics

Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.43	0.987	0.9827	0.9646	3	
2FI	0.3	0.9948	0.9916	0.9827	1.47	Suggested
Quadratic	0.37	0.9953	0.9874	0.9615	3.27	
Cubic	0.59	0.9959	0.9676	0.2608	62.73	Aliased

4.6.2 ANOVA

In order to specify the influence of input parameters on the drying time, Analysis of Variance (ANOVA) method is used. two-factor interaction (2FI) model is suggested for the drying time with Prob > F of < 0.0001 and model F-value of 317.11 which implies the model is significant as shown in Table 4.18 below. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. The value of Prob > F which is less than 0.0500 indicates the model terms are significant. In this case, the type of nozzle design (A) and the interaction between different type of nozzle design and insulation (AB) are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. In this case, the type of insulation (B) is not a significant model as it has a Prob > F value of 0.1001.

Table 4.18: ANOVA table for drying time

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	84.42	3	28.14	317.11	< 0.0001	significant
A	83.40	1	83.40	939.88	< 0.0001	
B	0.36	1	0.36	4.06	0.1001	
AB	0.66	1	0.66	7.39	0.0418	
Residual	0.44	5	0.089			
Cor Total	84.86	8				

4.6.3 Regression Statistic

In Table 4.19 below, the value Pred R-squared of 0.9827 shows that it is reasonable agreement with the value Adj R-squared of 0.9916. The R-squared shows a value of 0.9948 which is very near to 1.000 considered desirable. The Adeq. Precision value measures the signal to noise ratio. With a ratio greater than 4, it is desirable and the ratio shown is 41.626 indicating an adequate signal. Hence, this model can be used to navigate the design space.

Table 4.19: Regression statistic

Std. Dev.	0.30	R-Squared	0.9948
Mean	14.69	Adj R-Squared	0.9916
C.V.	2.03	Pred R-Squared	0.9827
PRESS	1.47	Adeq Precision	41.626

4.6.4 Final Equations

Table 4.20 below shows the table to generate the final equation in terms of the coded factors. The final equation in terms of coded factors is generated by considering the coefficient estimate along with the factor. The coefficient estimate is multiplied to the factors.

Table 4.20: Table to generate final equation in terms of coded factors

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	14.69	1	0.099	14.43	14.94	
A-Type of Nozzle Design	3.73	1	0.12	3.42	4.04	1
B-Type of Insulation	-0.24	1	0.12	-0.56	0.068	1
AB	0.41	1	0.15	0.022	0.79	1

Final Equation in Terms of Coded Factors:

Drying Time = + 14.69 + 3.73 (A) - 0.24 (B) + 0.41 (A * B) Equation 4.5

Final Equation in Terms of Actual Factors:

Drying Time = + 11.60944 + 3.32333 (Type of Nozzle Design) - 0.65 (Type of Insulation) + 0.405 (Type of Nozzle Design * Type of Insulation) Equation 4.6

4.6.5 Diagnostics Case Statistics

Table 4.21 below shows the diagnostics case statistics. The diagnostics case statistics is a compilation of data to be used for regression analysis in order to seek for assessment in the validity of a model in any number with different ways. In this case, the diagnostics case statistics contain data for various types of diagnostics graphs such as the normal probability plot, residual vs. predicted plot, residual vs. run plot, residual vs. factor plot, outlier T plot, Cook's distance plot, leverage plot, predicted vs. actual plot and lastly the Box Cox plot.

Table 4.21: Diagnostics case statistics

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	11.83	11.61	0.22	0.694	1.339	1.019	1.496	9
2	14.53	14.93	-0.40	0.278	-1.591	0.243	-2.025	1
3	18.38	18.26	0.12	0.694	0.752	0.322	0.715	2
4	10.75	10.96	-0.21	0.278	-0.827	0.066	-0.797	4
5	15.03	14.69	0.34	0.111	1.219	0.046	1.300	8
6	18.40	18.42	-0.016	0.278	-0.064	0.000	-0.057	3
7	10.43	10.31	0.12	0.694	0.732	0.305	0.693	5
8	14.24	14.44	-0.20	0.278	-0.801	0.062	-0.767	6
9	18.60	18.58	0.024	0.694	0.145	0.012	0.130	7

4.6.6 Model Diagnostics Plots

The model diagnostics plot shows the plot of residual on how well the models satisfy the assumption of ANOVA. The Figure 4.12 (a) below shows the normal probability plot of residual for the drying time. It reveals that a check point on the plots that the residual generally falls on a straight line implying the errors is distributed normally. While Figure 4.12 (b), Figure 4.12 (c), and Figure 4.12 (d) shows the residual vs. the predicted plot, residuals vs. type of nozzle design plot and residual vs. type of insulation plot, respectively. From these three plots, it can be observed that there are no unusual pattern and outliers found throughout the plots.

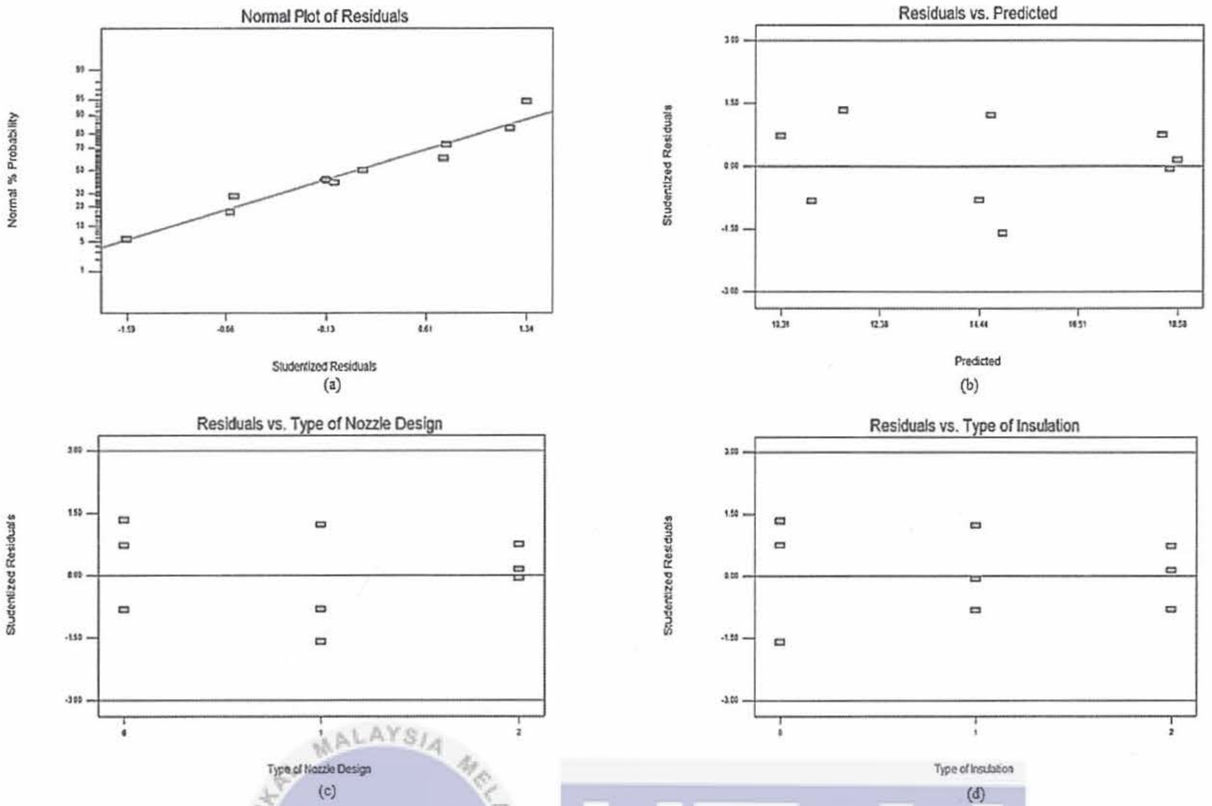


Figure 4.12: (a) Normal plot vs. residuals, (b) Residuals vs. predicted plot, (c) Residuals vs. type of nozzle design plot, (d) Residuals vs. type of insulation plot.

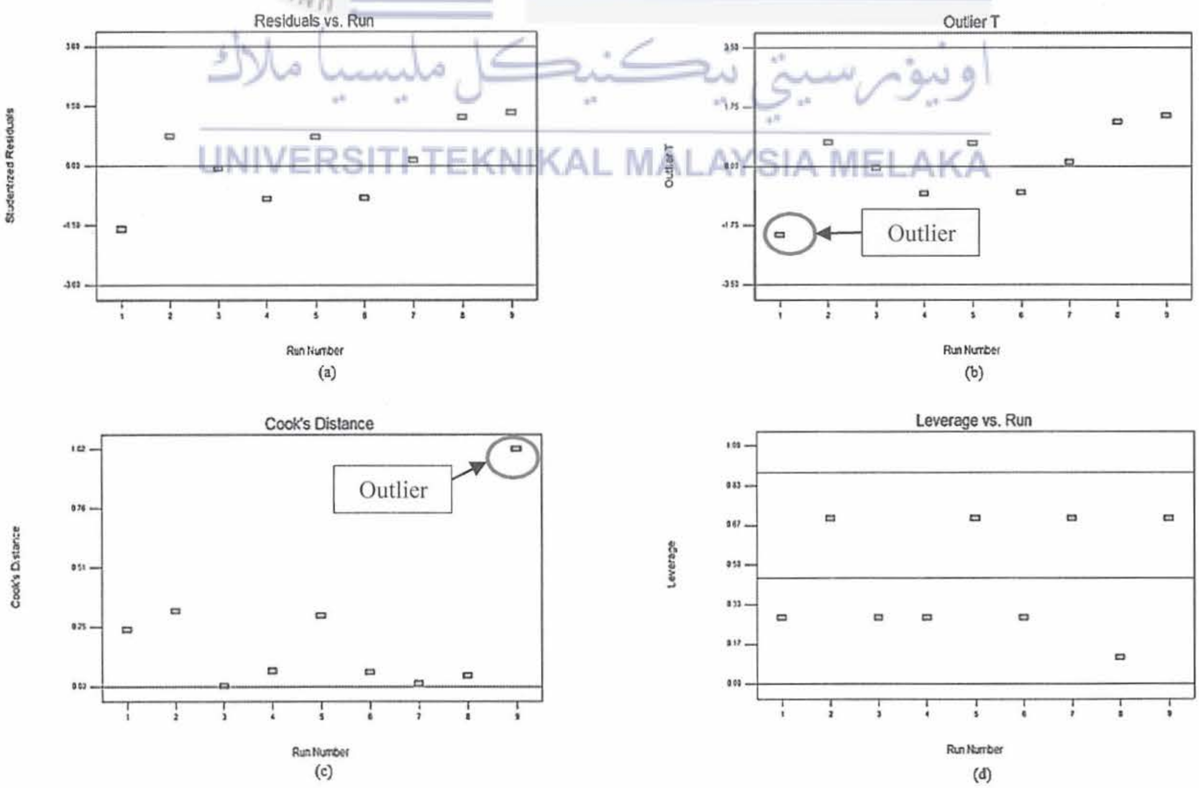
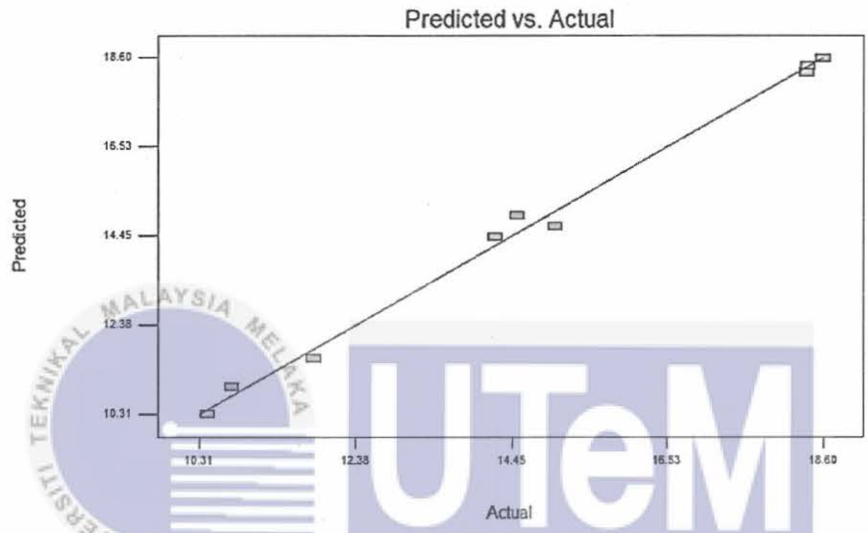
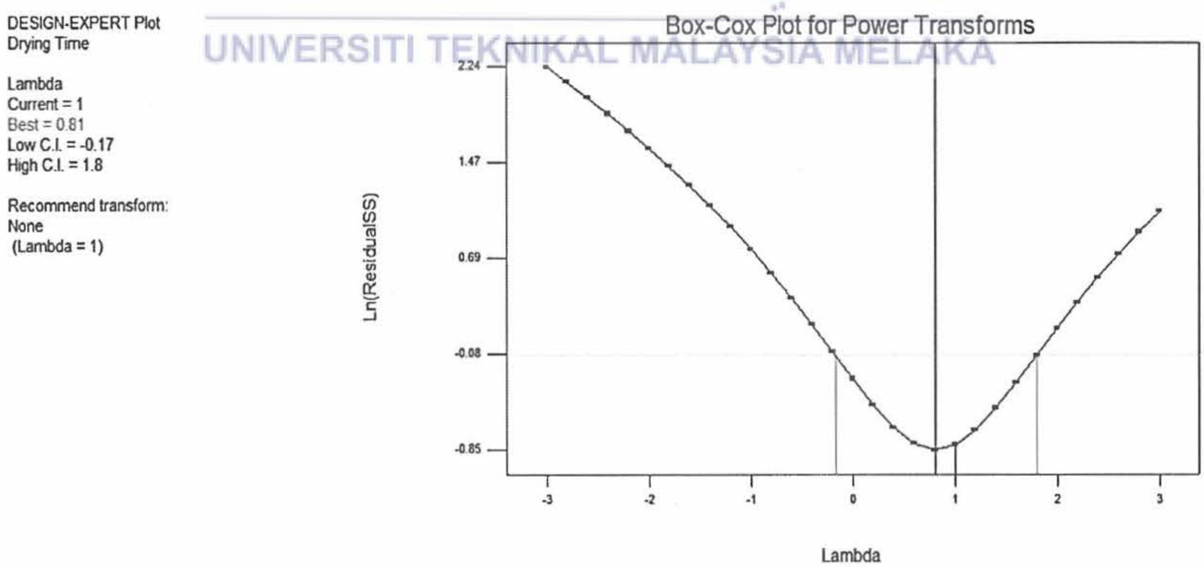


Figure 4.13: (a) Residuals vs. run plot, (b) Outlier T plot, (c) Cook's distance plot, (d) Leverage vs. run plot.

On the other hand, Figure 4.13 (a), Figure 4.13 (b), Figure 4.13 (c) and Figure 4.13 (d) above shows the residual vs. run plot, outlier T plot, Cook's distance plot and leverage vs. run plot, respectively. The residual vs. run plot shows a random scatter with no lurking variables detected. The outlier T plot has an outlier detected at the 1st run number of design point while the Cook's distance plot has an outlier at the 9th run number of design point. As for the leverage vs. run plot, the design points are consistent throughout the graph which gives a random scatter pattern.



(a)



(b)

Figure 4.14: (a) Predicted vs. actual plot, (b) Box-Cox plot for power transforms.

The above Figure 4.14 (a) shows the predicted vs. actual plot while Figure 4.14 (b) shows the Box-Cox plot for power transforms. The predicted vs. actual plot shows the effect of the model by comparing it against the null model. In this case, the points on the graph are relatively close to the fitted line with narrow confidence bands without any possible outliers being detected. Thus, the predicted vs. actual plot has a good fit. On the other hand, the Box-Cox plot for power transforms interpret that the value of Lambda is equivalent to 1. Thus, no transformation is needed. In this case, the best lambda value is 0.81 provided that both of the low and high confidence interval (C.I.) values are -0.17 and 1.8, respectively.

4.6.7 Perturbation Plot of Drying Time

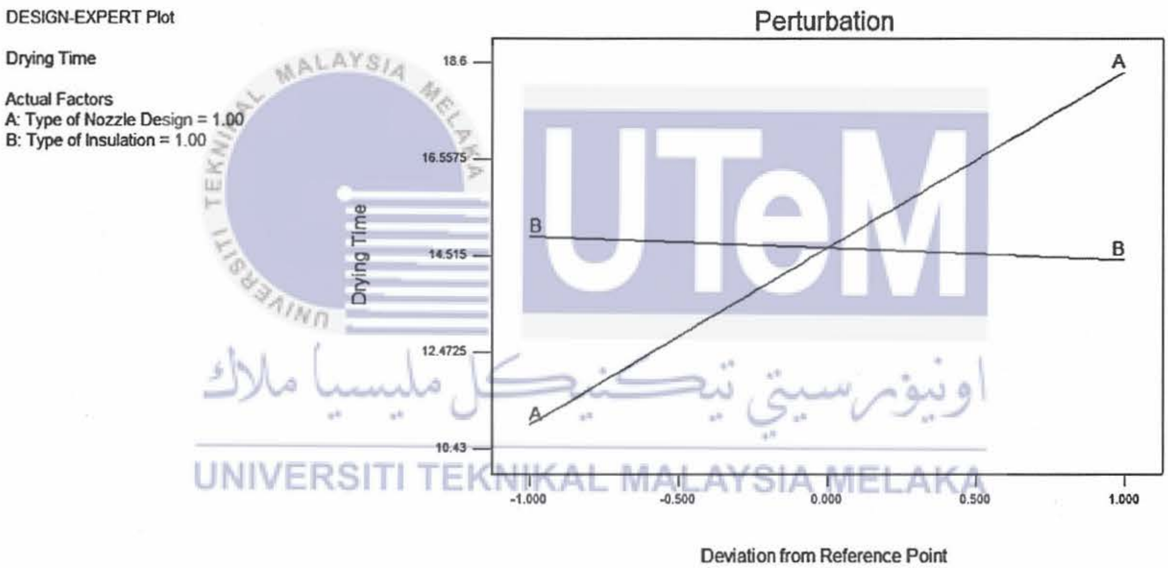


Figure 4.15: Perturbation plot of drying time

The Figure 4.15 above shows the perturbation plot of the drying time. In general, the perturbation plot is used to study the effect of specific factors towards the response in the design space. The relatively flat line suggests insensitivity to change in that specific factors. While the steepest curvature indicates the factor that is most significantly affects the response. Factor A and B are the type of nozzle design and type of insulation, respectively as shown in the Figure 4.15 above. Both of the Factors A and B were deviated at a distance of 1.000 from the default reference point of 0.000. In this case, both Factor A and Factor B can be considered as the factors that are insensitivity to change in the drying time of the hand dryer since both of these factors are relatively flat lines.

4.6.8 3D Surface Plot of Drying Time

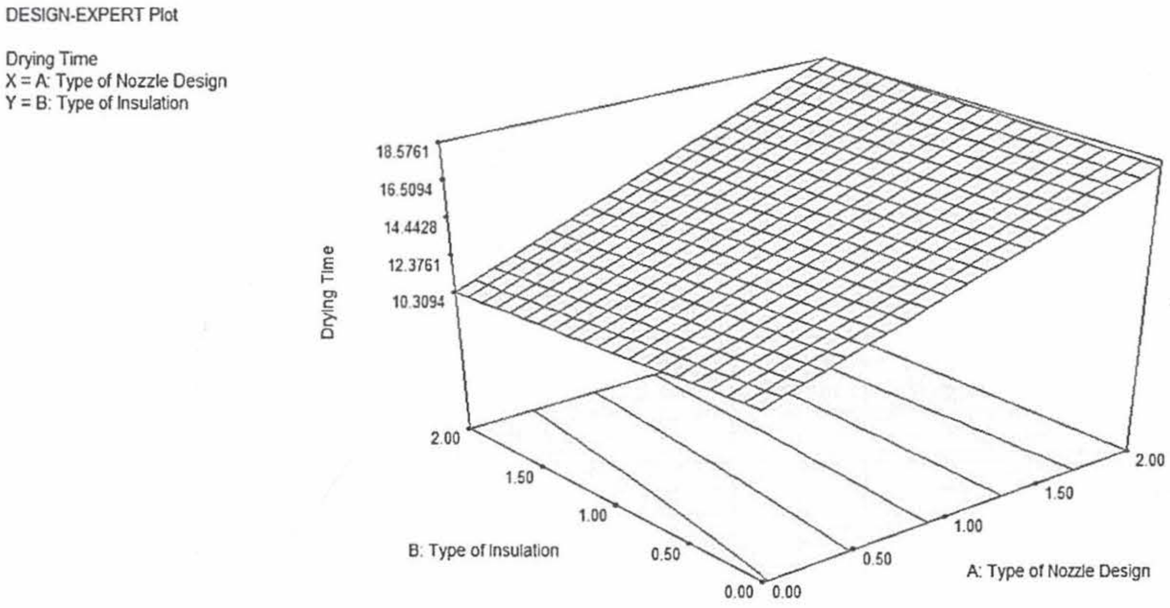


Figure 4.16: 3D surface plot of drying time

Figure 4.16 above shows the 3D surface plot for the factor type of nozzle design and type of insulation with response to drying time. It can be observed that the shortest drying time is obtained when the type of nozzle design is 0.00 and the type of insulation is 2.00. This also indicates that the type of nozzle design is the chrome nozzle while the type of insulation is the pyramid foam. Thus, this can also be considered as the best possible combination of factors that is able to achieved the most desirable output response which is the minimum drying time at an approximate value of 10.7415 s according to the Solution 1 suggested in Table 4.23.

4.7 Optimization of The Parameters

After the optimization process, there are two solutions suggested to show the best combinations of parameters in order to obtain the most ideal response which are maximum air velocity, minimum noise level and minimum drying time. In this case, the solution 1 has the highest desirability compared to solution 2 as shown in Table 4.23. Solution 1 is chosen as it has lower noise level and drying time and comparable air velocity compared to solution 2. The best combination of parameters which in terms of the type of nozzle design and the type of insulation are 0.00 and 1.34, respectively.

The numerical value of 0.00 for the type of nozzle design represents the chrome nozzle. While the numerical value of 1.34 for the type of insulation represents the combination of two types of insulation which are the wedge foam (1.00) and pyramid foam (2.00) whereby the ratio of pyramid foam is higher than the wedge foam. The solution 1 will produce air velocity of 45.7975 MPH, noise level of 77.165 dB and drying time of 10.7415 s which has the highest desirability of 0.900.

Table 4.22: Table of constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Type of Nozzle Design	is in range	0	2	1	1	3
Type of Insulation	is in range	0	2	1	1	3
Air Velocity	maximize	21.18	46.07	1	1	5
Noise Level	minimize	76	82	1	1.22945	5
Drying Time	minimize	10.43	18.6	1	1	5

Table 4.23: Solutions for optimization of parameters

Number	Type of Nozzle Design	Type of Insulation	Air Velocity	Noise Level	Drying Time	Desirability	
1	0.00	1.34	45.7975	77.165	10.7415	0.900	Selected
2	0.00	1.31	45.9873	77.1873	10.7589	0.900	

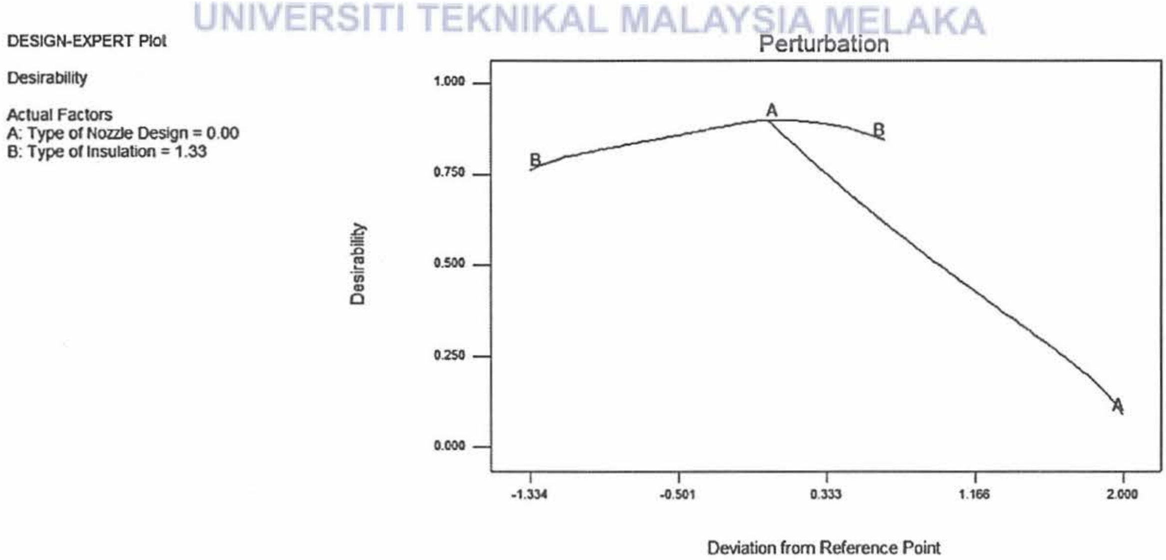


Figure 4.17: Perturbation plot of desirability

The Figure 4.17 above shows the perturbation plot of the desirability. In general, the perturbation plot is used to study the effect of specific factors towards the response in the design space. The relatively flat line suggests insensitivity to change in that specific factors. While the steepest curvature indicates the factor that is most significantly affects the response. Factor A and B are the type of nozzle design and type of insulation, respectively as shown in the Figure 4.17 above. In this case, Factor A can be considered as the factor that can significantly affects the air velocity since it has the steepest curvature compared to the Factor B.

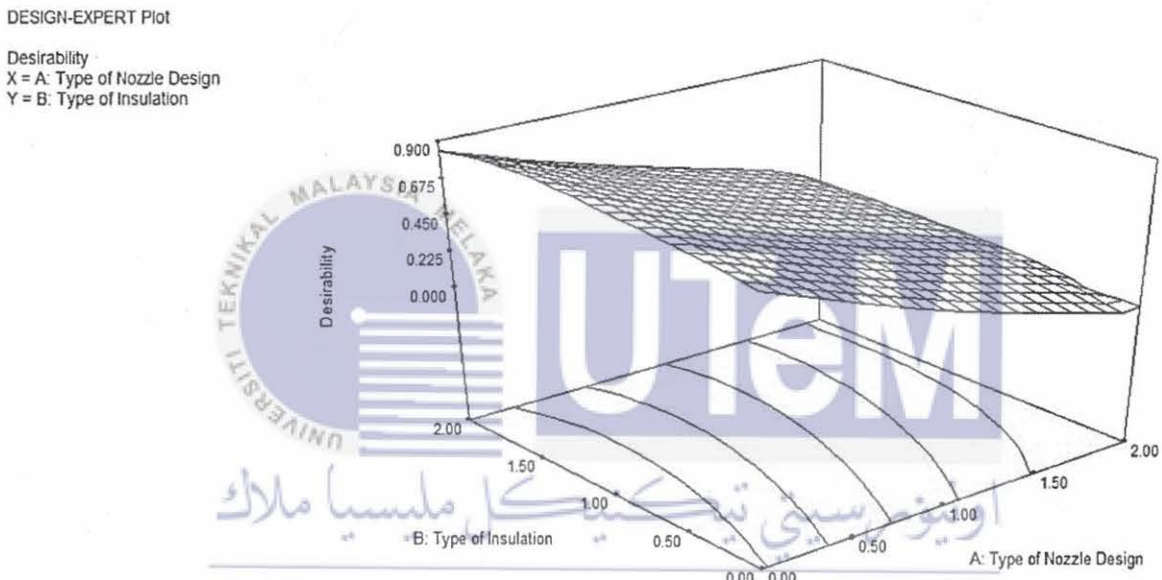


Figure 4.18: 3D surface plot of desirability

Figure 4.18 above shows the 3D surface plot for the factor type of nozzle design and type of insulation with response to desirability. It can be observed that the highest desirability of all three responses in terms of the air velocity, noise level, and drying time can be obtained when the type of nozzle design is 0.00 and the type of insulation is 1.33. This also indicates that the type of nozzle design is the chrome nozzle while the type of insulation is a combination of two types of insulations which are the pyramid foam and wedge foam. Thus, this can also be considered as the best possible combination of factors that is able to achieved the most desirable output response which is the maximum air velocity at an approximate value of 45.7975 MPH, minimum noise level at an approximate value of 77.165 dB, and minimum drying time at an approximate value of 10.7415 s, all according to the Solution 1 suggested in Table 4.23.

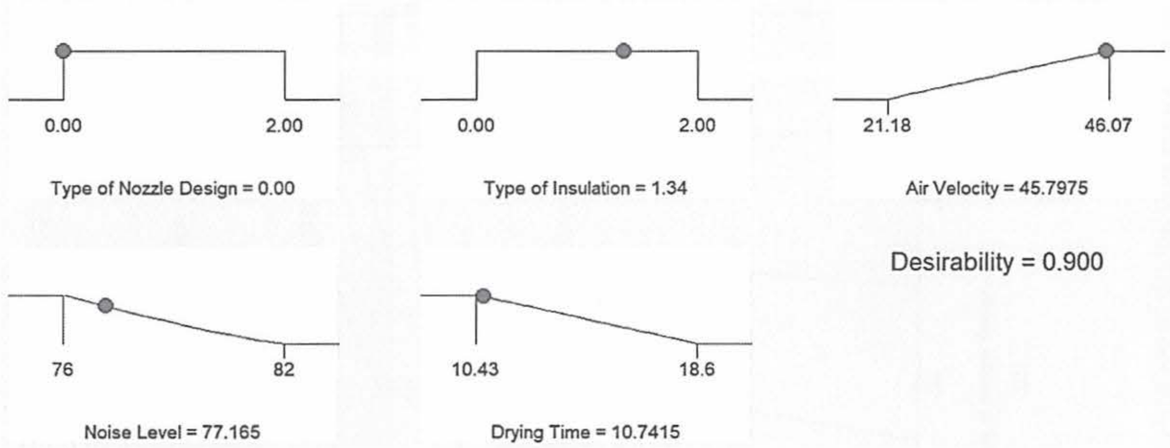


Figure 4.19: Ramp function graph

Figure 4.19 above shows the details to achieve the requirements for maximum air velocity, minimum noise level and minimum drying time. The upward slope for the air velocity indicate the desired response at the maximum value, whereas the downward slope for both the noise level and drying time indicate the desired response at the minimum value. The minimum type of nozzle design (0.00) and type of insulation (1.34) produce the highest air velocity, lowest noise level and drying time with the desirability of 0.900.

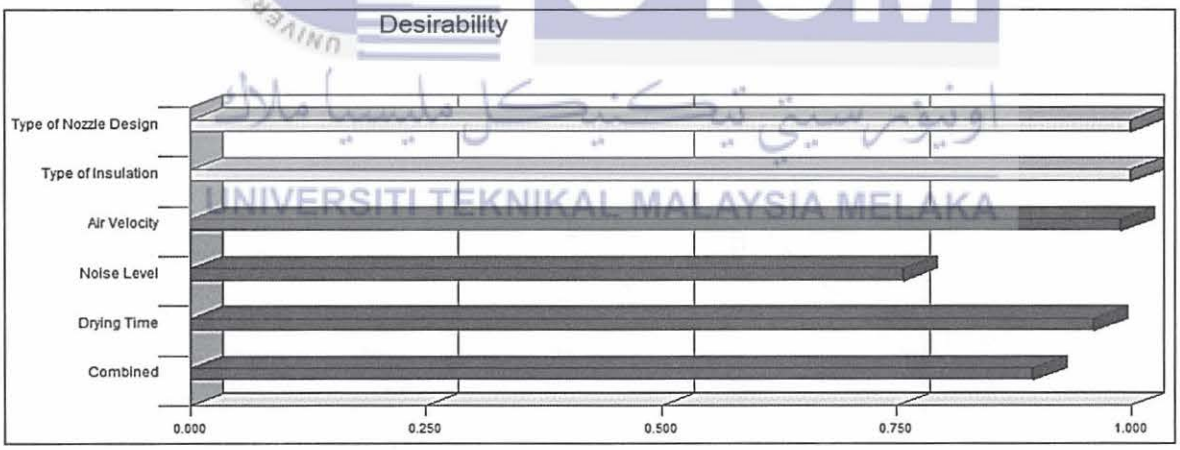


Figure 4.20: Histogram of Desirability

The Figure 4.20 above shows the histogram of desirability for solution 1. From the histogram, it can be clearly observed that the level of desirability for both of the input parameters which are the type of nozzle design and the type of insulation have the highest desirability. While next followed by the air velocity, drying time, combined factors and lastly the noise level which has the lowest level of desirability among all factors and responses. Still, the desirability of the noise level is beyond average level.

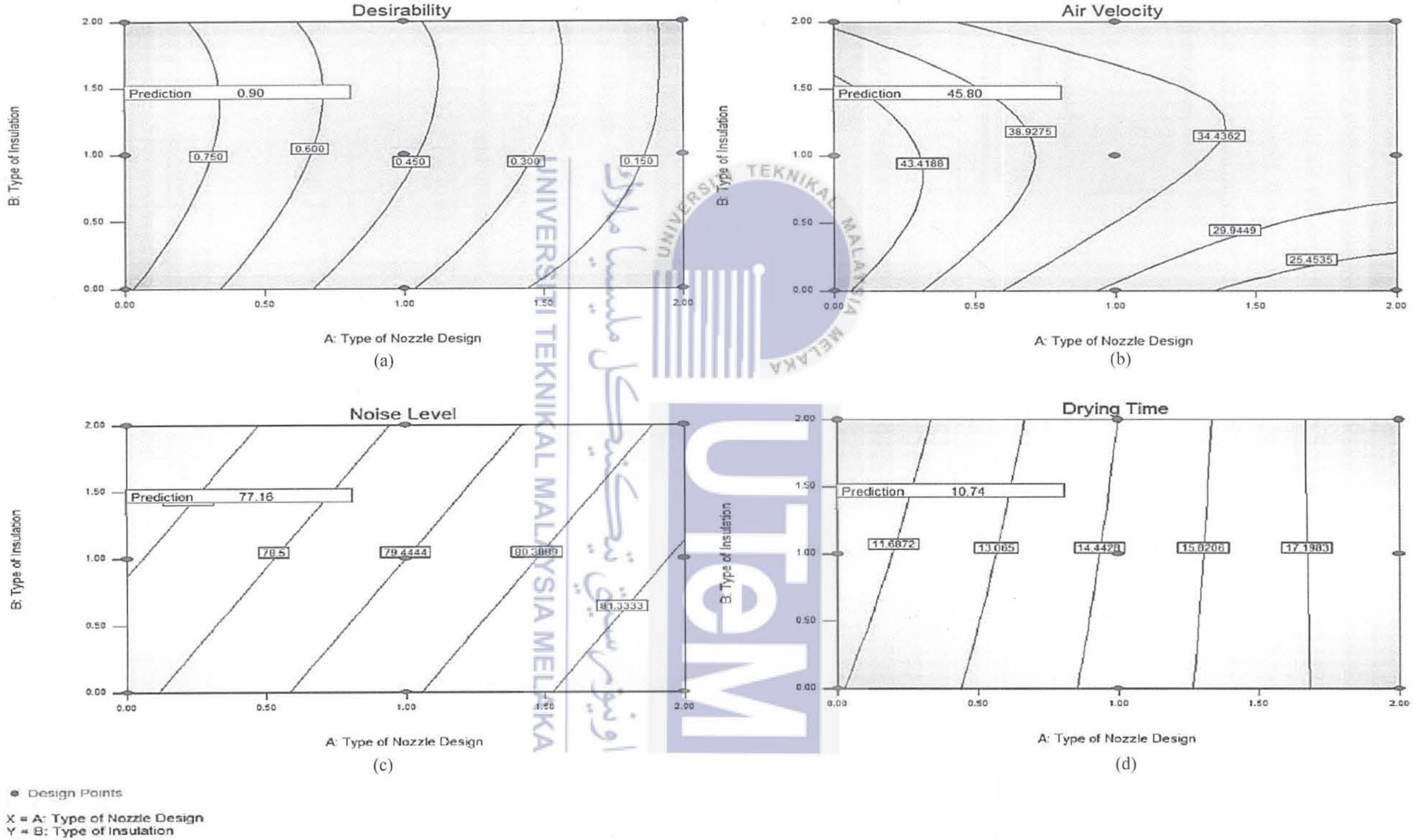


Figure 4.21: (a) Desirability plot, (b) Optimization of air velocity plot, (c) Optimization of noise level plot, (d) Optimization of drying time plot.

The Figure 4.21 above shows the result of graph after optimization. Based on the desirability plot, the prediction value of the desirability after optimization is 0.90. While the optimization of air velocity plot shows a prediction value of 45.80 MPH after optimization. On the other hand, the optimization of noise level plot shows a prediction value of 77.16 dB, while the optimization of drying time plot shows a prediction value of 10.74 s after optimization.

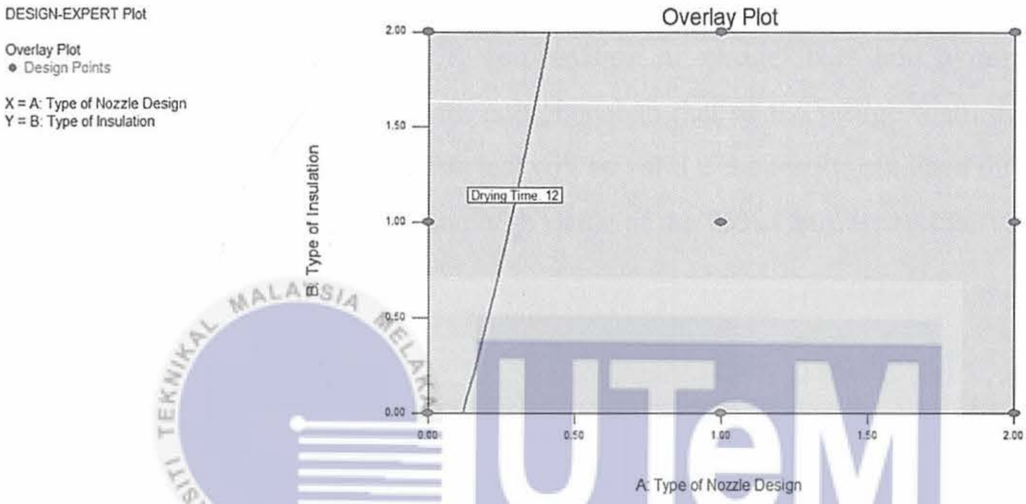


Figure 4.22: Overlay Plot

Figure 4.22 above shows an overlay plot. The overlay plot shows drying time of 12 s, provided that the boundary limit of air velocity is set at 20 MPH and 50 MPH for lower and upper limit, respectively. While the boundary limit of noise level is set at 65 dB and 75 dB for lower and upper limit, respectively. As for the boundary limit of drying time, it is set at 8 s and 12 s for lower and upper limit, respectively.

4.8 Validation Test Through Actual Experiment

Table 4.24: Design factor specifications

Factor	Name	Level	Low Level	High Level	Std. Dev.
A	Type of Nozzle Design	0.000	0.000	2.00	0.000
B	Type of Insulation	1.34	0.000	2.00	0.000

Table 4.25: Optimization of responses

	Prediction	SE Mean	95% CI low	95% CI high	SE Pred	95% PI low	95% PI high
Air Velocity	45.7633	1.11	42.23	49.30	1.88	39.77	51.75
Noise Level	77.1611	0.45	76.06	78.26	0.94	74.87	79.45
Drying Time	10.7384	0.17	10.30	11.18	0.34	9.86	11.62

Table 4.24 above shows the design factor specifications while Table 4.25 shows the optimization of responses. Based on the design factor specifications from Table 4.24, the suggested type of nozzle design is the chrome nozzle with its numerical value of 0.00, while suggested the type of insulation is the combination of wedge foam and pyramid foam provided that the ratio of pyramid foam is higher than that of the wedge foam during the validation test. In addition, the validation test will be valid if the results obtained through the actual experiment are within the low and high range of the 95% Confidence Interval (CI).

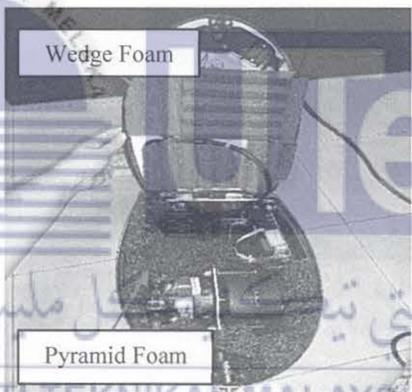


Figure 4.23: Pyramid and wedge foam installed in the internal motor housing and cover of hand dryer

The Figure 4.23 above shows the installation of pyramid foam and wedge foam as an insulation barrier in the internal motor housing and the cover of hand dryer. As shown in the figure above, the wedge foam was attached to the wall of the hand dryer cover while the pyramid foam was attached to the wall of the internal motor housing by using double sided tape to secure in place. After that, the experiment with this set up was carried out three times along with the combination of chrome nozzle being inserted into the air outlet.

Since the suggested model of optimization is 0.00 for the type of nozzle design and 1.34 for the type of insulation in terms of numerical value, this indicate that the type of nozzle design used for the experiment should be the chrome nozzle while the type of nozzle design that should be used is the combination of wedge foam and pyramid foam whereby the ratio of the wedge foam is lesser than that of the pyramid foam used as the insulation barrier in the internal housing of the hand dryer motor. After the readings of air velocity, noise level and drying time has been collected, the data will be compiled and validation test will be conducted based on the actual value of the experimental versus the predicted value generated by the Design Expert software.

Table 4.26: Data Collection of Responses

Readings	1	2	3	Average
Air Velocity (MPH)	45.96	46.55	49.05	47.19
Noise Level (dB)	77	77	77	77
Drying Time (s)	10.40	10.73	10.76	10.63

After the actual experiment has been conducted based on the suggested factors from solution 1, the data was collected and the average of each response were calculated from 3 runs of experiments. The Table 4.26 above shows the data collection of the responses with respect to the average. While the Table 4.27 below shows the measurement between the predicted versus actual value in terms of the air velocity, noise level and drying time. The Equation 4.7 below is used to calculate the relative error between the predicted and actual value.

$$\textit{Relative error}\ (\%) = \left|\frac{\textit{Predicted value} - \textit{Actual value}}{\textit{Predicted value}}\right| \times 100\% \qquad \text{Equation 4.7}$$

Table 4.27: Measurement between the predicted versus actual value in terms of the air velocity, noise level and drying time

Type of Nozzle Design	Type of Insulation	Air Velocity (MPH)		Relative error for air velocity (%)
		Predicted	Actual	
Chrome Nozzle (0.00)	Wedge + Pyramid (1.34)	45.7633	47.19	3.12
Type of Nozzle Design	**Type of Insulation**	**Noise Level (dB)**		**Relative error for noise level (%)**
		Predicted	**Actual**	
Chrome Nozzle (0.00)	Wedge + Pyramid (1.34)	77.1611	77	0.21
Type of Nozzle Design	**Type of Insulation**	**Drying Time (s)**		**Relative error for drying time (%)**
		Predicted	**Actual**	
Chrome Nozzle (0.00)	Wedge + Pyramid (1.34)	10.7384	10.63	1.01

Based on the results above, it is observed that the actual value of air velocity is higher than the predicted value, whereas the actual value of noise level and drying time are lower than the predicted value. Besides, the relative error for all three of the responses are below 5% which indicates that the results are validated. This statement can also be supported by comparing each of the responses to their respective low and high range of the 95%

Confidence Interval (CI) based on Table 4.25. If the value obtained through the actual experiment is within the range of the 95% Confidence Interval (CI), the model is said to be validated.

In terms of the first response which is the air velocity, the actual value obtained through experiment is 47.19 MPH which is the average from 3 runs of experiment. By referring back to Table 4.25, the actual value of the air velocity has actually falls within the low and high range of 95% CI which was given the reading of 42.23 MPH and 49.30 MPH, respectively. While in terms of the second response which is the noise level, the actual value obtained through experiment is 77 dB which is the average from 3 runs of experiment. By referring back to Table 4.25, the actual value of the noise level has actually falls within the low and high range of 95% CI which was given the reading of 76.06 dB and 78.26 dB, respectively.

As in terms of the third response which is the drying time, the actual value obtained through experiment is 10.63 s which is the average from 3 runs of experiment. By referring back to Table 4.25, the actual value of the drying time has actually falls within the low and high range of 95% CI which was given the reading of 10.30 s and 11.18 s, respectively. On the other hand, the relative error for the air velocity, noise level and drying time are 3.12%, 0.21%, and 1.01%, respectively.

There are several possible factors that might lead to the occurrence of relative error of the responses. Firstly, in terms of the air velocity, the possible factor could be the surrounding air flow is relatively high and comparable to the hand dryer air flow which causes fluctuation of the readings for a period of 10 minutes to 20 minutes depending on each situations. Secondly, in terms of the noise level, the possible factor could be the presence of background sound such as the buzzing noise coming out from the air conditioner in a closed room. Lastly, the possible factor in terms of the drying time for the wetness of the hands is different for a few times which causes slight difference in drying time.

4.9 Comparison Between Default Readings and Improvised Readings

Table 4.28: Default readings without nozzle and insulation

	Reading 1	Reading 2	Reading 3	Average
Air Velocity (MPH)	48.46	46.90	47.80	47.72
Noise Level (dB)	86	85	85	85.33
Drying Time (s)	14.37	15.26	14.98	14.87

Table 4.29: Comparison between default and improvised (with nozzle and insulation) readings

	Default Readings	Improvised Readings	Difference
Air Velocity (MPH)	47.72	47.19	0.53
Noise Level (dB)	85.33	77	8.33
Drying Time (s)	14.87	10.63	4.24

Based on the Table 4.28 above, the default readings were obtained from the average for all three readings of each input parameters. The Table 4.29 above shows the comparison between default and improvised (with nozzle and insulation) readings. The difference of air velocity between the default readings and the improvised readings is 0.53 MPH which indicates that the improvised model has given a slight reduction of 0.53 MPH in terms of the air velocity as compared to the default setting of hand dryer. Next, the difference of noise level between the default readings and the improvised readings is 8.33 dB which indicates that the improvised model has given a reduction of 8.33 dB in terms of the noise level as compared to the default setting of hand dryer.

Lastly, the difference of drying time between the default readings and the improvised readings is 4.24 s which indicates that the improvised model has given a reduction of 4.24 s in terms of the drying time as compared to the default setting of hand dryer. Overall, the result of the improvised model which applied the combination of chrome nozzle with wedge foam and pyramid foam is considered to have improved the overall effect of hand dryer fan parameter on the noise and aerodynamic level.

4.10 Summary

In summary, it can be concluded that from the results of analysis obtained in the Design of Experiment (DoE), the best combination of the type of nozzle design and insulation that has been suggested by the software are the chrome nozzle with the combination of wedge foam and pyramid foam as the insulation used in the internal motor housing of the hand dryer. All three of these parameters combination has given the most desirable output and has achieved the aim of this project which is to have the lowest noise level, shortest drying time and highest air velocity. Furthermore, this has also proven that the effect of hand dryer fan parameter which involved the combination of chrome nozzle with wedge foam and pyramid foam has produced the greatest impact on the noise reduction and aerodynamic level of the hand dryer.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.0 Conclusion

In this project, it can be concluded that the outcomes of this research has successfully fulfilled all three of the main objectives in this study. The first objective which is to investigate the existing default design of the hand dryer model. This has been conducted in prior of the Design of Experiment (DoE) in order to keep a record of the original output for the purpose of comparison with the improvised model of hand dryer in which external factors such as the applications of various types of nozzle design and insulations are to be considered during the data collection stage in DoE.

The second objective is to analyse the correlation between the input parameters and the response. In terms of this objective, it can be observed that from the result obtained in data collection prior to DoE, the combination of diffuser nozzle and egg carton has the least desirable outputs as it produced the lowest air velocity with highest noise level and longest drying time. While the most desirable combination of parameters are the chrome nozzle and wedge foam as both of these have contributed the highest air velocity with lowest noise level and shortest drying time. The mid-range results between these two combinations are the combination of concentrator nozzle and pyramid foam.

The third objective is to suggest the best combinations of input parameters that gives the optimum response in order to obtain the best result. In terms of this objective, the best combinations of input parameters are the combination of chrome nozzle with wedge foam and pyramid foam which eventually gives the most desirable output of 47.19 MPH of air velocity, 77 dB of noise level and 10.63 s of drying time. This gives an approximate reduction of 8.33 dB in terms of the noise level, a slight reduction of 0.53 MPH of air velocity and a reduction of 4.24 s in terms of the drying time, between the original experiment (default hand dryer setting) and the experiment with consideration of input parameters.

As for the scope of this study, the first scope is to find the optimum air velocity at minimum noise level with acceptable drying time. In terms of this scope, it has been observed that the optimum velocity is 47.19 MPH, provided that the minimum noise level is at 77 dB while the acceptable drying time is 10.63 s. The second scope is to propose optimum flow directing outlet design (shape and dimension) with respect to air flow rate. In this case, the optimum directing outlet design is the chrome nozzle which gives an average of approximately 43.41 MPH from all the possible combination of various insulations. The third scope is to propose additional damping mechanism and noise insulator on the component in which there are three types of insulations that have been proposed and applied throughout the experiment which include the egg carton, wedge foam and pyramid foam.

Lastly, from the results of analysis obtained in the Design of Experiment (DoE), the best combination of the type of nozzle design and insulation that has been suggested by the software are the chrome nozzle with the combination of wedge foam and pyramid foam as the insulations used in the internal motor housing of the hand dryer. All three of these parameters combination has given the most desirable output and have achieved the aim of this project which is to have the lowest noise level, shortest drying time and highest air velocity. Furthermore, this has also proven that the effect of hand dryer fan parameter which involved the combination of chrome nozzle with wedge foam and pyramid foam has produced the greatest impact on the reduction of noise level and aerodynamic level of the hand dryer.

5.1 Future Recommendation

In this project, there are several future recommendations that can be implemented. First, the method of conducting the experiment can be improvised in a much better way in future by using the moisture level meter to monitor the level of moisture content of an individual's hand while using the hand dryer. Second, a moisture sensor can also be implemented by connecting the moisture sensor to a piece of wet cloth. At the same time, the signals detected by the moisture sensor will be translated and generated in the form of an Internet of Things (IoT) Arduino code to a connected computer device. Lastly, another method that can be used to determine the moisture content by ensuring a more accurate drying time is by weighing a piece of cloth with a weighing scale when it is in both wet and dry condition which is before and after a specific round of experiment has been conducted.

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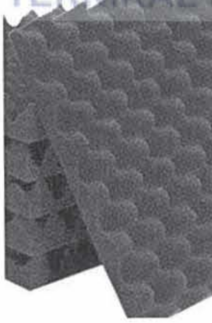
APPENDIX A

Various types of air outlet design shape:

Rubber coupling and motor mounting:

Various soundproofing acoustic foam:



APPENDIX B

Polyurethane (PU) acoustic foam:

Retrieved From: https://metatronfabrics.com/products/soundproof-foam-acoustic-panel-absorption-12-pack-kit-pyramid-24-x-24-x-2inch-studio-wall-soundproofing-blocking-absorbing

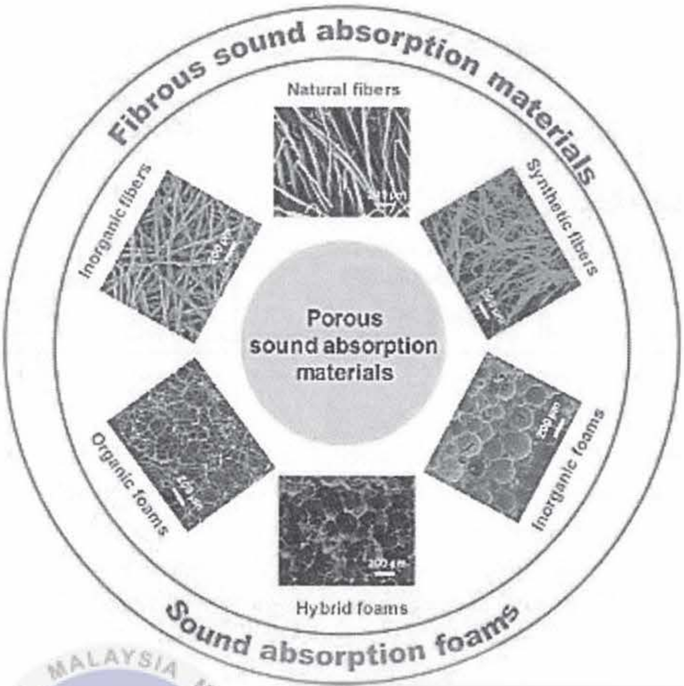
Sound level meter:

Retrieved From: https://www.fluke.com/en-us/product/building-infrastructure/indoor-air-quality-testing/fluke-945

Soundproof box:

Retrieved From: https://www.semillas-de-marihuana.com/en/soundproofing/2031-soundproof-box.html

Porous material for sound absorption:



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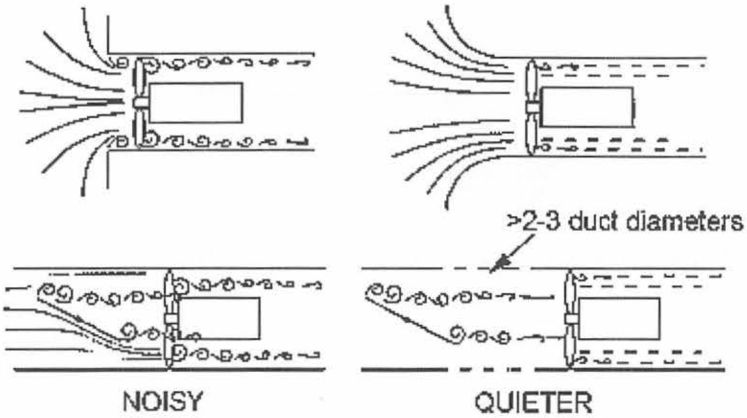
https://www.researchgate.net/publication/325614788_Porous_materials_for_sound_absorption

Partial enclosure barrier setup surrounding the noise source:

Retrieved From: https://acoustics.asn.au/conference_proceedings/AAS2017/papers/p55.pdf

Axial flow fan installations:



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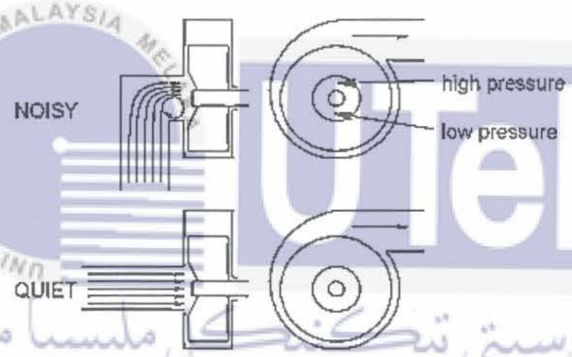
Centrifugal fan installations:



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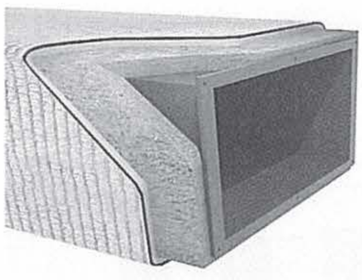
Acoustic barrier for ducting:

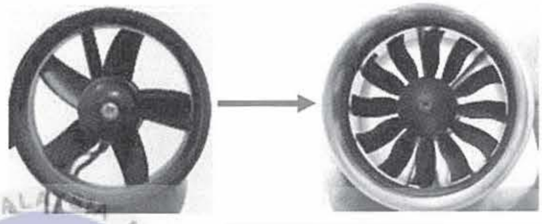


Retrieved From: https://buildingproductsearch.co.uk/listing/siderise-dwx-acoustic-barrier-for-ducting/

Rubber motor mounting:

Retrieved From: https://www.poly-tek.com/rubber-engine-mounts-vs-polyurethane-engine-mounts/

The number of fan blades increased from 5 blades to 12 blades:



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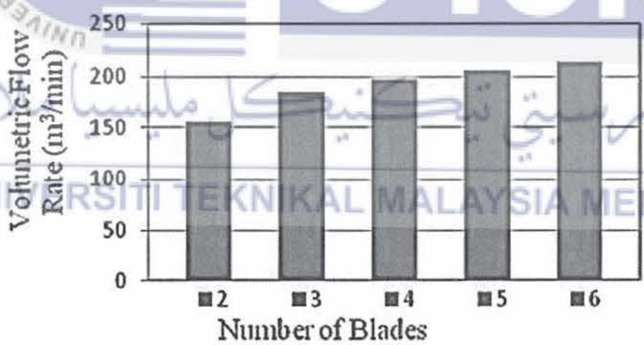
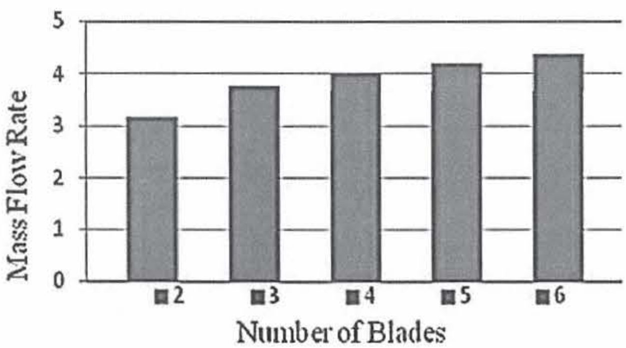
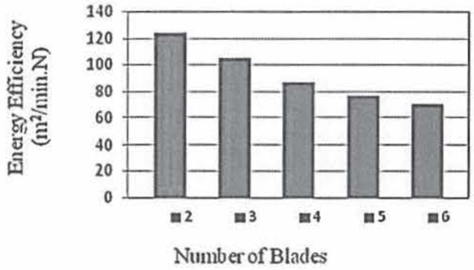
Volumetric flow rate vs. number of blades:



Mass flow rate vs. number of blades:



Energy efficiency vs. number of blades:



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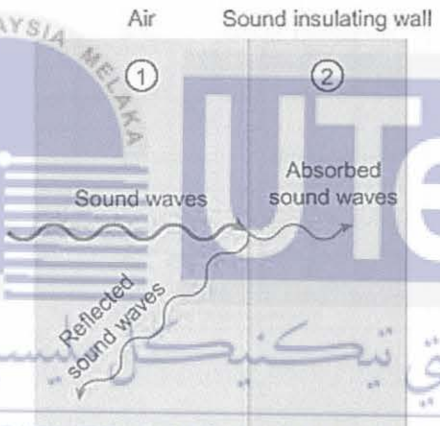
Sound absorption and reflection of an insulated wall:



Retrieved From:
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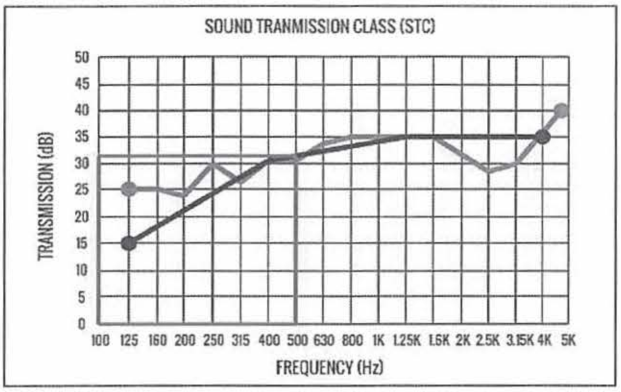
Noise Reduction Coefficient (NRC) ratings:

Noise Reduction Coefficient (NRC) Ratings					
Range	1" Wedge	2" Wedge	3" Wedge	4" Wedge	Bass Traps
125 Hz	0.14	0.2	0.25	0.39	1.18
250 Hz	0.17	0.29	0.47	0.61	1.27
500 Hz	0.36	0.66	0.83	0.91	1.26
1000 Hz	0.47	0.8	0.82	0.79	1.19
2000 Hz	0.51	0.89	0.92	0.95	1.16
4000 Hz	0.61	1.02	1.04	1.03	1.16
Overall	0.4	0.65	0.75	0.8	1.2

Retrieved From: https://www.soundassured.com/blogs/blog/what-is-noise-reduction-coefficient-nrc

Sound Transmission Class (STC):



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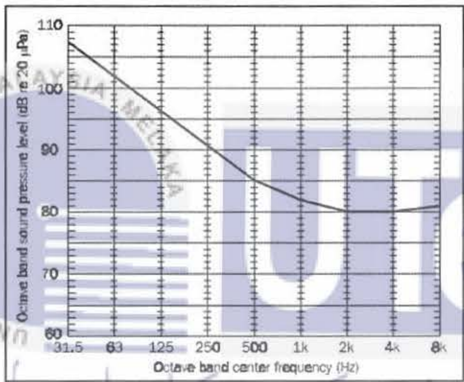
A-weighting of a desired noise spectrum:



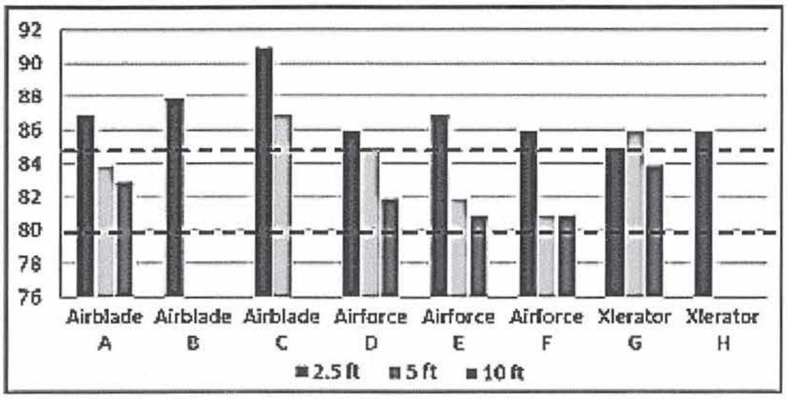
Retrieved From: https://www.who.int/occupational_health/publications/noise10.pdf

Measurements of sound intensity in dBA:

Table 1: Measurements of sound intensity in dBA

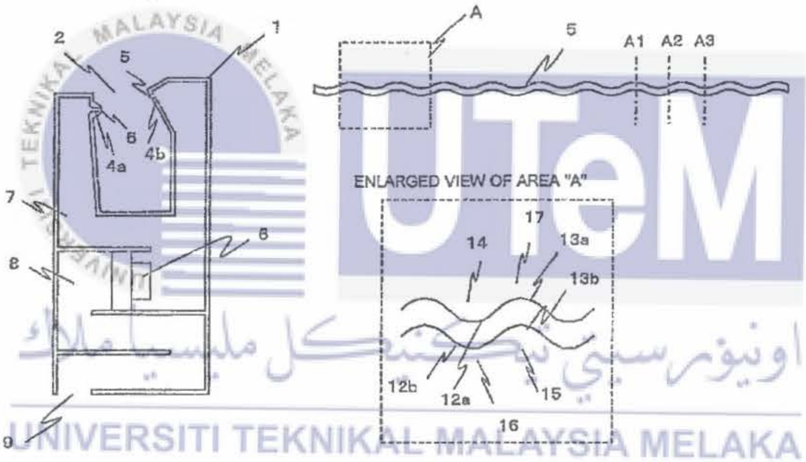
Room	Manufacturer	Model	Specs	2.5 ft average	5 ft average	10 ft average
A	Dyson	Airblade	85	87	84	83
B	Dyson	Airblade	85	88		
C	Dyson	Airblade	85	91	87	
D	World Dryer	Airforce	88	86	85	82
E	World Dryer	Airforce	88	87	82	81
F	World Dryer	Airforce	88	86	81	81
G	Excel Dryer	XLERATOR	80	85	86	84
H	Excel Dryer	XLERATOR	80	86		
			Mean	87.00	84.17	82.20

Average sound intensity in dBA for hand dryers in eight bathrooms:



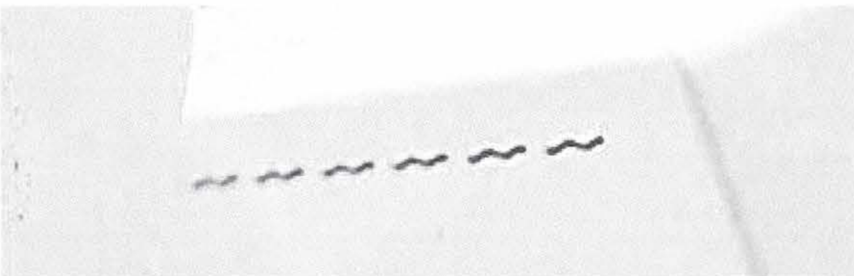
Retrieved From:
https://www.researchgate.net/publication/273638179_Hand_dryer_noise_in_public_restrooms_exceeds_80_dBA_at_10_ft_3_m

Section view of wave-shaped slit air nozzle:



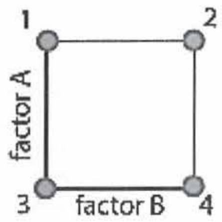
Retrieved From: https://patents.google.com/patent/US9220381

Mitsubishi Electric Jet Towel air nozzles:



Retrieved From: https://www.linkedin.com/pulse/how-choose-quieter-hand-dryer-neil-butler/

2^2 Full factorial design:

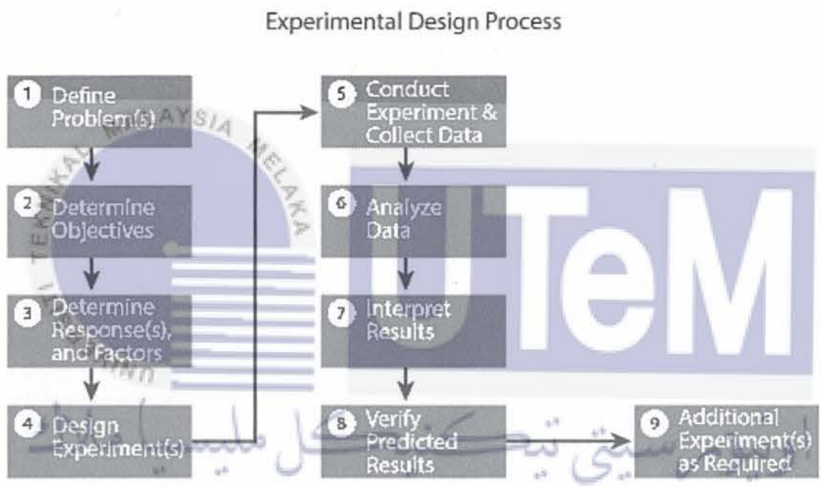


factor levels

trial	A	B
1	+	–
2	+	+
3	–	–
4	–	+

Retrieved From:
https://community.asdlib.org/imageandvideoexchangeforum/2013/08/05/modeling-response-surfaces-using-factorial-designs/

Experimental design process:



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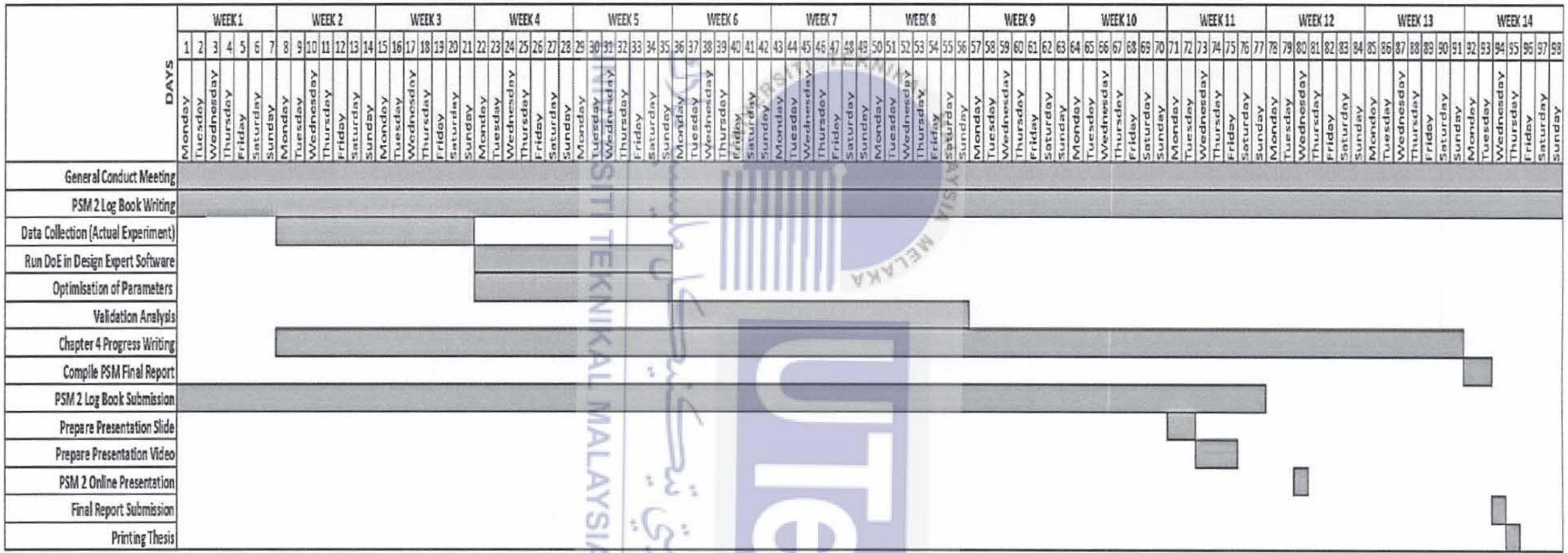
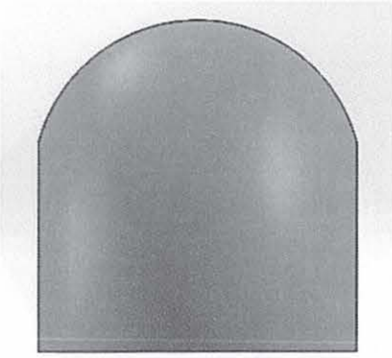
APPENDIX C

PSM 2 Gantt Chart:

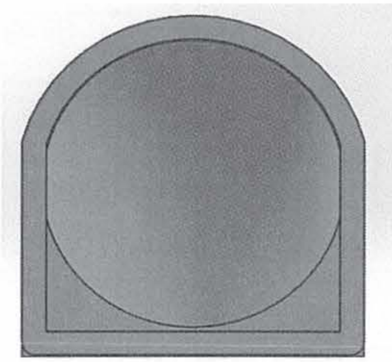


APPENDIX D

<u>**Name of Part: Chrome Nozzle (Type A)**</u>

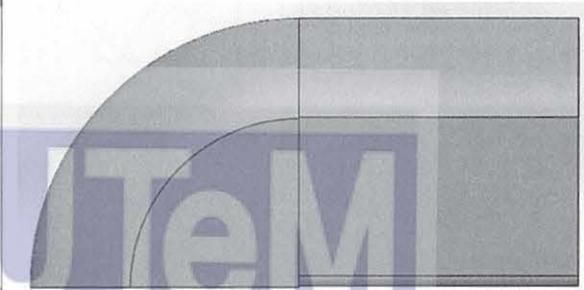


Front View

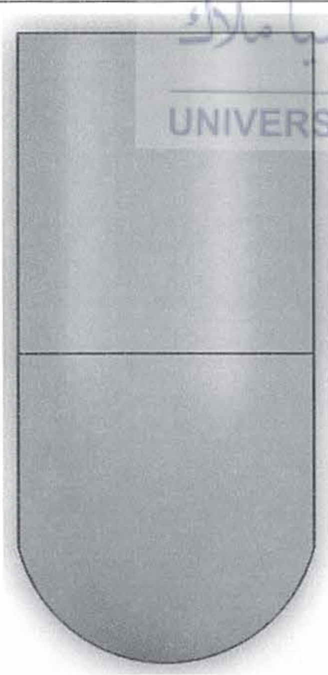


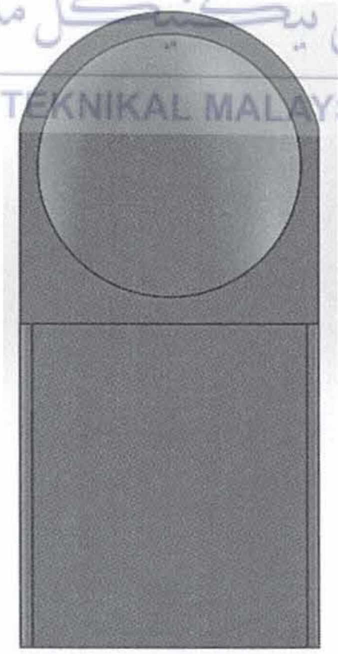
Back View

Left View



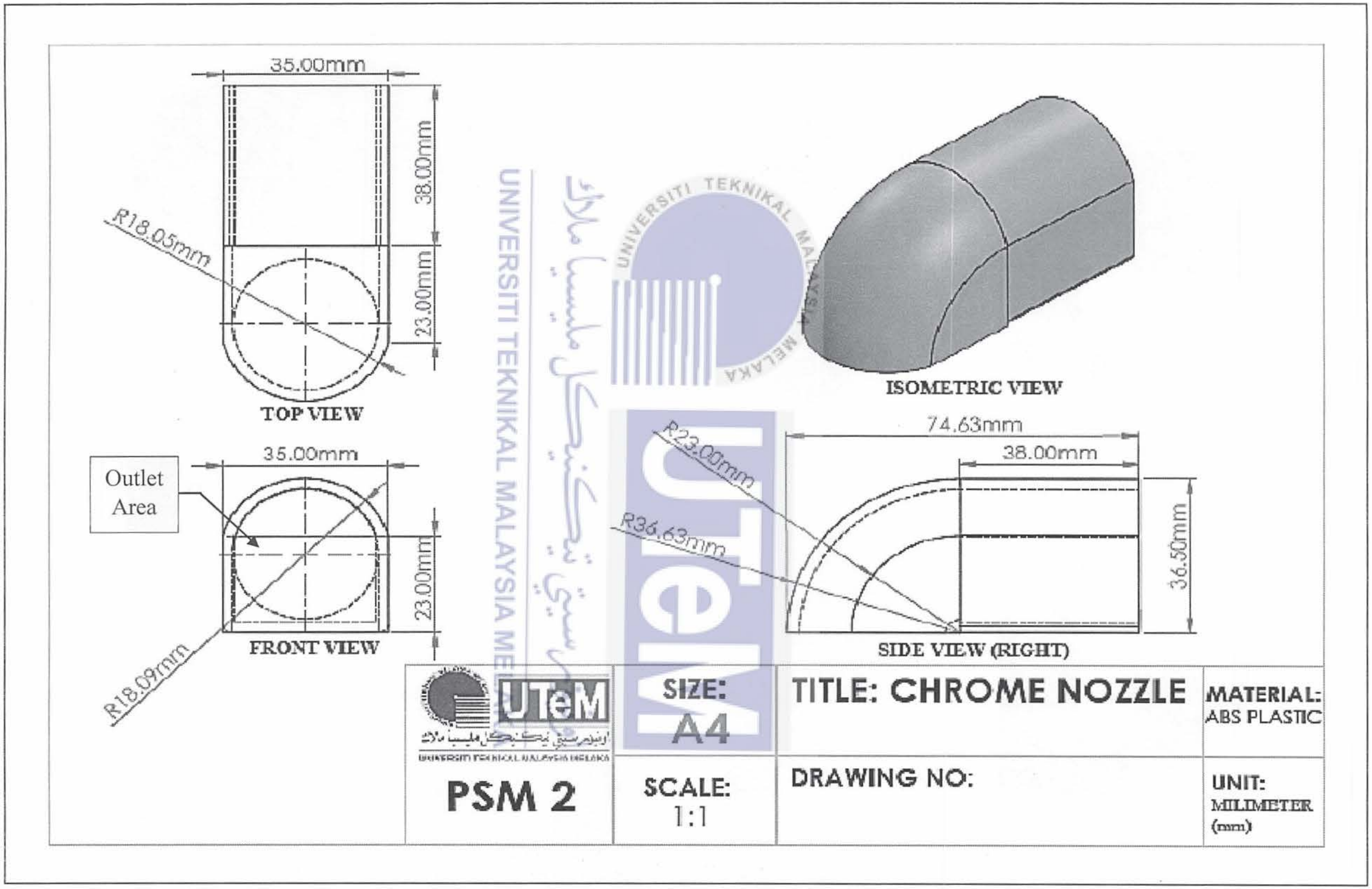
Right View



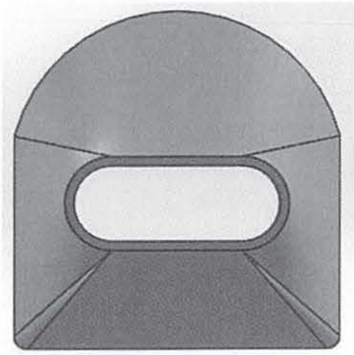


Isometric View

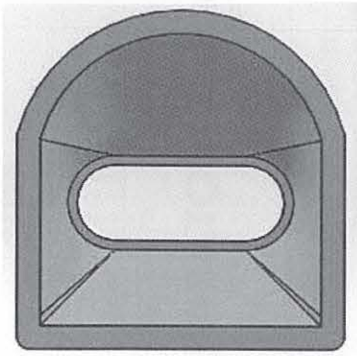
3D Printing Result


35.00mm
38.00mm
23.00mm
R18.05mm
TOP VIEW
35.00mm
Outlet Area
23.00mm
R18.09mm
FRONT VIEW
ISOMETRIC VIEW
74.63mm
38.00mm
R23.00mm
R36.63mm
36.50mm
SIDE VIEW (RIGHT)
PSM 2
SIZE: A4
SCALE: 1:1
TITLE: CHROME NOZZLE
DRAWING NO:
MATERIAL: ABS PLASTIC
UNIT: MILIMETER (mm)

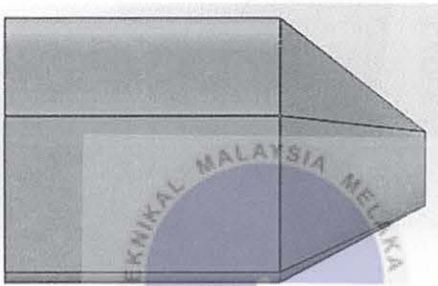
Name of Part: Concentrator Nozzle (Type B)



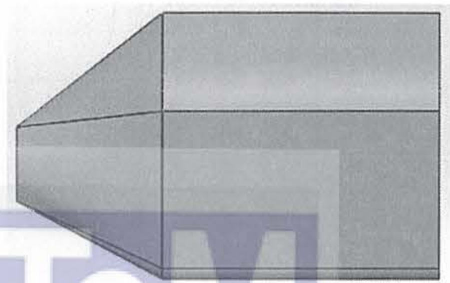
Front View



Back View

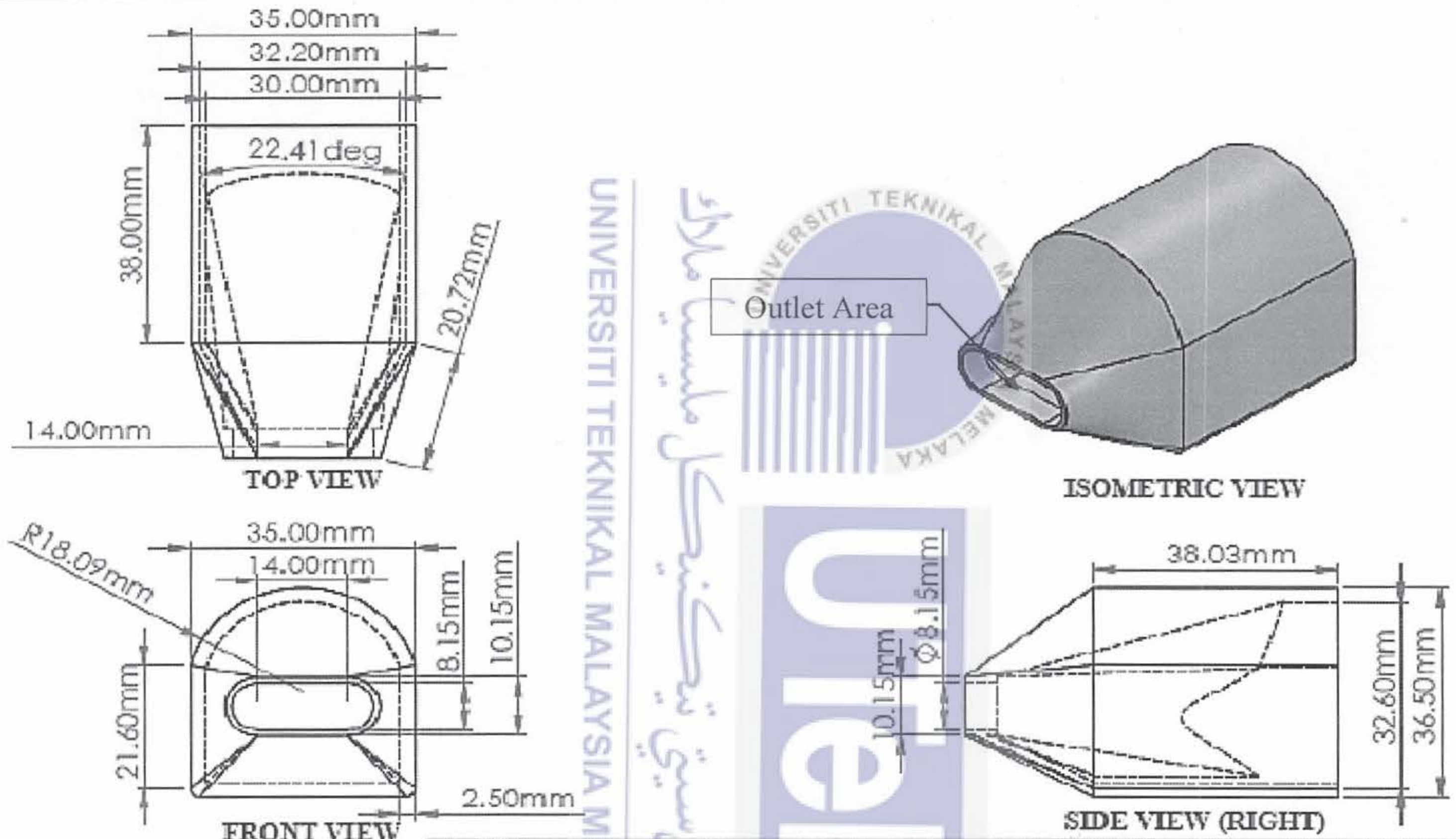


Left View



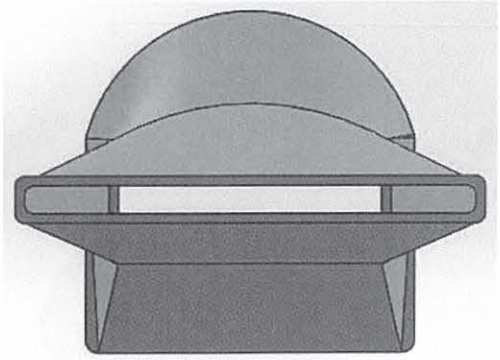
Right View

3D Printing Result

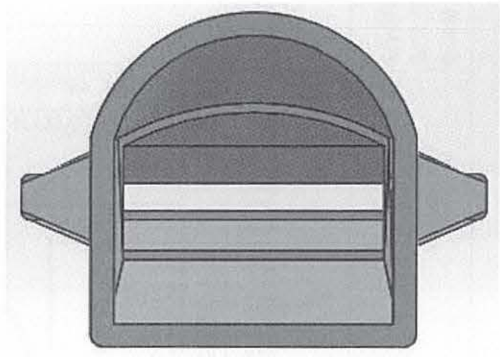


UTeM UNIVERSITI TEKNIKAL MALAYSIA MELAKA	SIZE: A4	TITLE: CONCENTRATOR NOZZLE	MATERIAL: ABS PLASTIC
PSM 2	SCALE: 1:1	DRAWING NO:	UNIT: MILIMETER (mm)

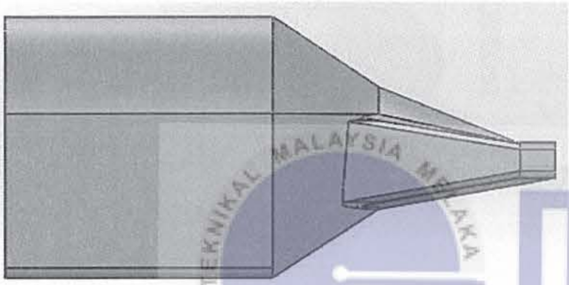
Name of Part: Diffuser Nozzle (Type C)



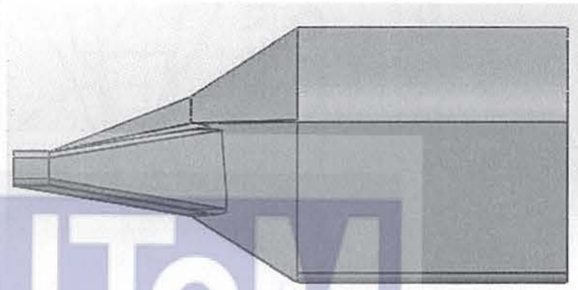
Front View



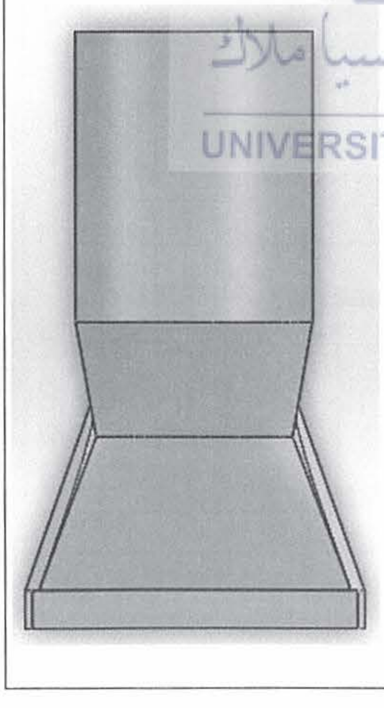
Back View

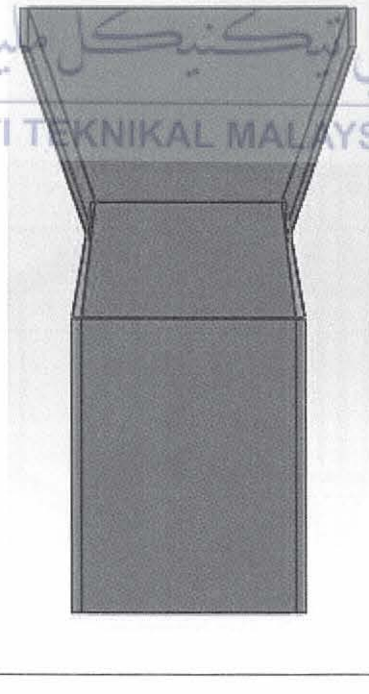


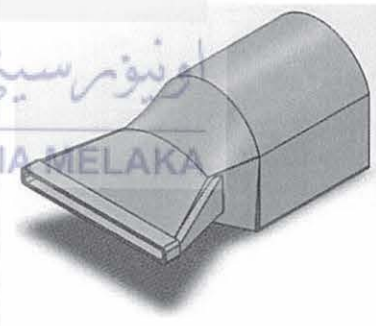
Left View

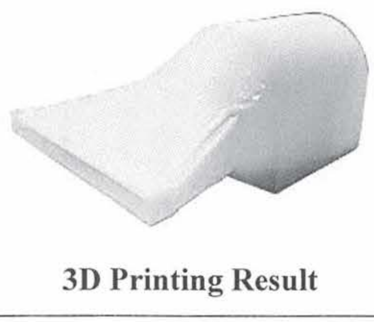


Right View

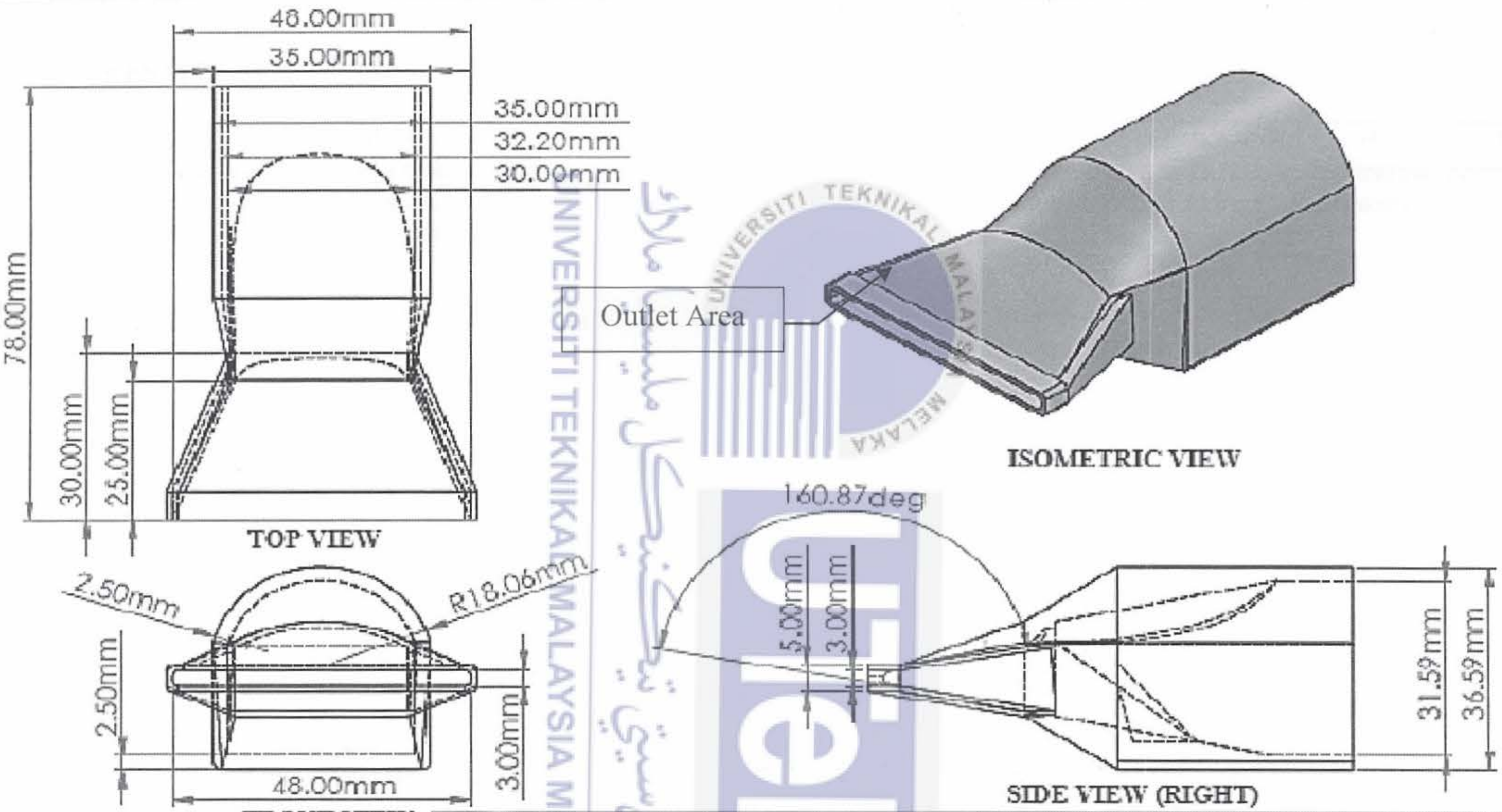








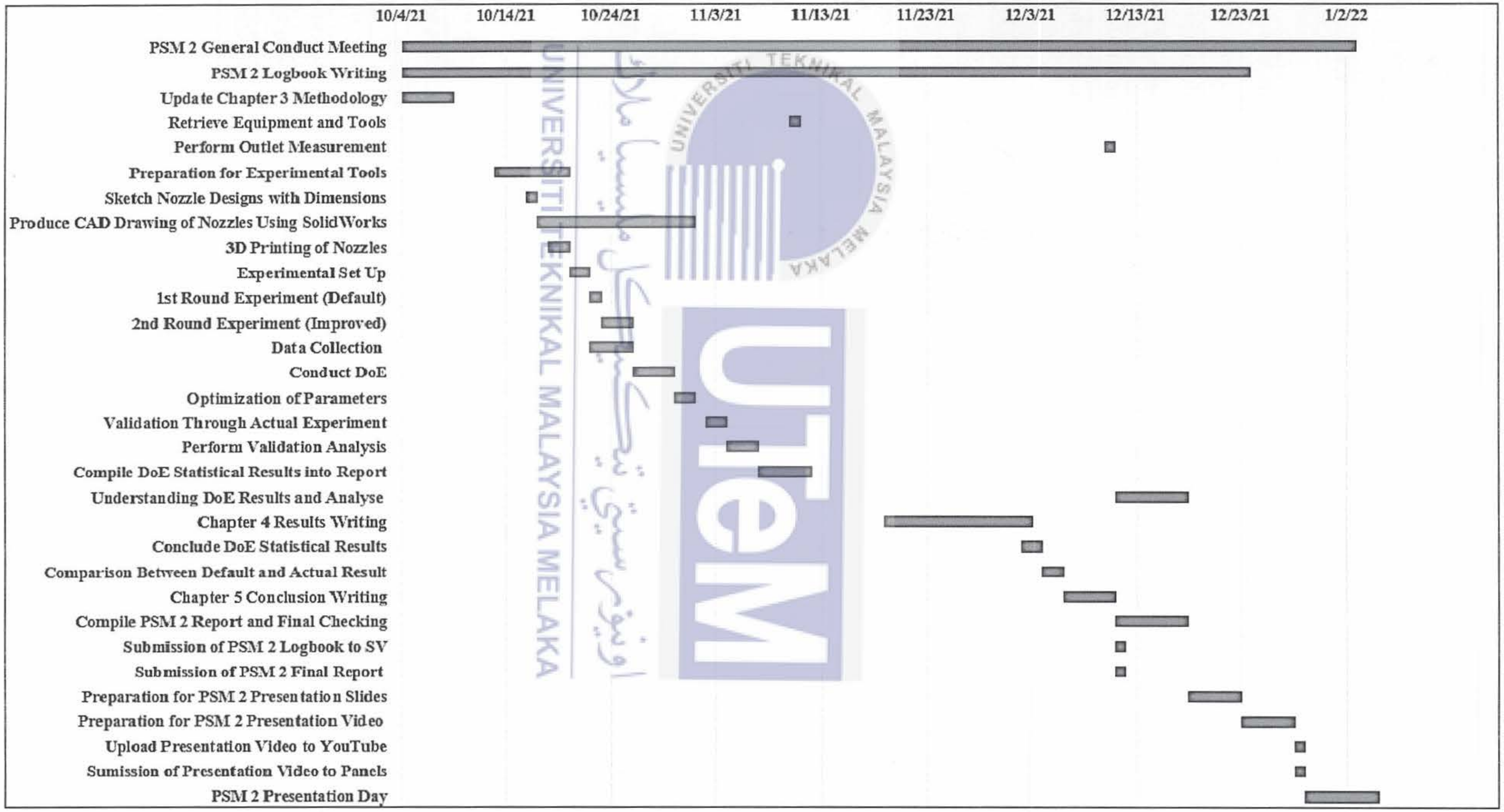
3D Printing Result



UTeM	SIZE: A4	TITLE: DIFFUSER NOZZLE	MATERIAL: ABS PLASTIC
PSM 2	SCALE: 1:1	DRAWING NO:	UNIT: MILIMETER (mm)

APPENDIX E

Gantt Chart for PSM 2:



Task Description	Start Date	Task Duration (Days)
PSM 2 General Conduct Meeting	10/4/21	91
PSM 2 Logbook Writing	10/4/21	81
Update Chapter 3 Methodology	10/4/21	5
Retrieve Equipment and Tools	11/10/21	1
Perform Outlet Measurement	12/10/21	1
Preparation for Experimental Tools	10/13/21	7
Sketch Nozzle Designs with Dimensions	10/16/21	1
Produce CAD Drawing of Nozzles Using SolidWorks	10/17/21	15
3D Printing of Nozzles	10/18/21	2
Experimental Set Up	10/20/21	2
1st Round Experiment (Default)	10/22/21	1
2nd Round Experiment (Improved)	10/23/21	3
Data Collection	10/22/21	4
Conduct DoE	10/26/21	4
Optimization of Parameters	10/30/21	2
Validation Through Actual Experiment	11/2/21	2
Perform Validation Analysis	11/4/21	3
Compile DoE Statistical Results into Report	11/7/21	5
Understanding DoE Results and Analyse	12/11/21	7
Chapter 4 Results Writing	11/19/21	14
Conclude DoE Statistical Results	12/2/21	2
Comparison Between Default and Actual Result	12/4/21	2
Chapter 5 Conclusion Writing	12/6/21	5
Compile PSM 2 Report and Final Checking	12/11/21	7
Submission of PSM 2 Logbook to SV	12/11/21	1
Submission of PSM 2 Final Report	12/11/21	1
Preparation for PSM 2 Presentation Slides	12/18/21	5
Preparation for PSM 2 Presentation Video	12/23/21	5
Upload Presentation Video to YouTube	12/28/21	1
Submission of Presentation Video to Panels	12/28/21	1
PSM 2 Presentation Day	12/29/21	7