DESIGN A LOW COST TABLE FAN USING DFMA ANALYSIS

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A report submitted
In fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "Design A Low Cost Table Fan Using DFMA Analysis" is the result of my work except as cited in the references.

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Date	:	....

APPROVAL

I hereby that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design & Innovation).

Signature :. ....

Name of Supervisor : DR MOHD AHADLIN BIN MOHD DAUD

Date : ....

DEDICATION

To my beloved mak and abah.

ABSTRACT

This project deals with study of Boothroyd Dewhurst Design for Manufacturing and Assembly (DFMA) method in terms of design efficiency to design a low cost table fan. DFMA is a method for designing or redesign product. The advantage of DFMA is able to deliver a systematic procedure to analyzing a proposed design from the point of view of assembly and manufacture, improve the design efficiency, minimize the cost production and fulfill customers' need. The total of part number table fan affecting the design efficiency of the product. To improve the design efficiency, the table fan is analyzed using DFMA method. The result of DFMA analysis is implemented in order to propose a new design of low cost table fan. The project was carried out through dismantle the unit of product, determined the function of each component by evaluating and compare the existing product using DFMA analysis. Lastly is implementing the DFMA analysis result and design guidelines to create a new design by generating a 3D modelling using CATIA V5R20 software. The selection criteria for a good design are based on number of part and operation time. DFMA analysis of optimized design is done and comparative analysis is made between the current and proposed design. The existing product design efficiency is 10.39% for National brand and 11.12% for Pensonic. Result shows that the design efficiency for proposed new design of table fan is obtained better percentage which is 16.61% rather than the existing design. . The final result shows that design efficiency for new design is increased by 5.49 to 6.22%. From the project findings, the number of parts is reduced to 15 parts and the operation time is 180.56s. Eventually, the improvement of table fan design that implemented from DFMA analysis result finally will be able to meet user requirements and satisfactions to design a low cost table fan

ABSTRAK

Projek ini berkaitan dengan kajian Boothroyd Dewhurst Design for Manufacturing and Assembly (DFMA) dari segi kecekapan reka bentuk untuk mereka bentuk kipas meja berkos rendah. DFMA adalah kaedah untuk mereka bentuk atau produk reka bentuk semula. Kelebihan DFMA mampu menyampaikan suatu prosedur yang sistematik untuk menganalisis reka bentuk yang dicadangkan dari sudut pandangan berhimpun dan pembuatan, meningkatkan kecekapan reka bentuk, mengurangkan kos pengeluaran dan memenuhi kehendak pelanggan. Jumlah bilangan bahagian kipas meja menjejaskan kecekapan reka bentuk produk. Untuk meningkatkan kecekapan reka bentuk, kipas tersebut dianalisis menggunakan kaedah DFMA. Hasil analisis DFMA yang dilaksanakan untuk mencadangkan reka bentuk baru kos rendah kipas meja. Projek ini telah dijalankan melalui pengurangan unit produk, ditentukan melalui fungsi setiap komponen dengan menilai dan membandingkan produk yang sedia ada dengan menggunakan analisis DFMA. Akhir sekali sedang melaksanakan hasil analisis DFMA dan garis panduan reka bentuk untuk menghasilkan reka bentuk yang baru melalui menjana pemodelan 3D menggunakan perisian CATIA V5R20. Kriteria pengambilan reka bentuk yang baik adalah berdasarkan kepada beberapa bahagian dan operasi semasa. Analisis DFMA reka bentuk dioptimumkan dilakukan dan analisis perbandingan dibuat antara reka bentuk semasa dan yang dicadangkan. Kecekapan reka bentuk produk sedia ada adalah 10.39% bagi jenama National dan 11.12% untuk Pensonic. Keputusan menunjukkan bahawa kecekapan reka bentuk untuk reka bentuk baru cadangan kipas meja diperolehi peratusan yang lebih baik iaitu 16.61% daripada reka bentuk yang sedia ada. . Keputusan akhir menunjukkan bahawa kecekapan reka bentuk untuk reka bentuk baru meningkat 5,49-6,22%. Dari dapatan projek, jumlah bahagian dikurangkan kepada 15 bahagian dan masa operasi adalah 180.56s. Akhir sekali, peningkatan reka bentuk kipas meja yang dilaksanakan dari hasil analisis DFMA akhirnya akan dapat memenuhi keperluan dan kepuasan pengguna dalam mereka bentuk kipas meja berkos rendah

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TM	=	Assembly time
TK	=	Operation cost
TPC	=	Theoretical minimum part count
NM	=	Theoretical minimal part
DE	=	Design Efficiency

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LIST OF SYMBOLS

E_{ma}	=	Assembly Efficiency
N_{min}	=	Theoretical minimum number of part
t_a	=	Basic assembly time for one part
t_{ma}	=	Estimated time to complete the assembly of the product

CHAPTER 1

INTRODUCTION

1.1 Background

Design for Manufacturing and Assembly (DFMA) is considered one of the main approaches to concurrent engineering which help in minimize production costs and development time by simplify the components of product to give higher profit to the manufacturer. DFMA combines two concepts of Design for Manufacturing (DFM) and Design for Assembly (DFA) (H. Eskelinen, 2013). The aims of DFA are to improve the products assembly by minimizing the part count and variation as well as reducing the variety of assembly instructions and complexity. Meanwhile, DFM are focusing to improve the product design at minimum cost of manufacturing for maximum manufacturing quality by using the efficient techniques and practices that available (W.A. Knight, 2005). Therefore, DFMA serve a systematic procedure to analyzing a proposed design from the point of view of assembly and manufacture, improve the design efficiency, minimize the cost production and fulfill customers' need (Mendosa, N., Ahuett, H., & Monila, A, 2003).

1.2 Problem Statement

The total part of table fan affecting the design efficiency of the product. The solution to improve the design efficiency is by analyzing using DFMA method. The result of DFMA analysis is implemented in order to propose a new design of low cost table fan.

1.3 Objective

The main objective of this study is to perform a research and development for manufacturing process on low cost table fan of two different brands by evaluate and compare the design efficiency of the products using DFMA Analysis and suggest the improvement that can be made on the product.

1.4 Scope of Study

The scope of this project is make a comparison the design efficiency of the table fan used for Design of Manufacturing and Assembly (DFMA) for:

1. To identify and select the type of product to studied.
2. To apply and analyse the design efficiency on table fan using Boothroyd Dewhrust (DFMA) method.
3. To compare both design efficiency of table fan.
4. To suggest the improvement to each design based on the DFMA Analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses about the Design for Manufacturing and Assembly (DFMA), Design for Assembly (DFA), Design for Manufacturing (DFM) and overview on previous study cases and perspective approach that related to this project.

2.2 Design for Manufacturing and Assembly

DFMA is the combination of Design for Manufacturing (DFM) and Design for Assembly (DFA). This means the concepts of DFM and DFA are working together which this method significant affects productivity, quality and cost of product and time to market. (Boothroyd, 2002). The fundamental concept of the DFMA paradigm is applied to analyse the manufacturing and assembly problems of a product on the early design stage. Generally, DFMA is used for three main activities as below:

i. As the basic for concurrent engineering studies that to provide guidance to the design team in simplifying the product structure, to reduce manufacturing and assembly costs and to quantify the improvements.
ii. As a benchmarking tool to study competitors' product and quantify manufacturing and assembly difficulties.
iii. As a should-cost tool to help control cost and helps negotiate supplier contracts.

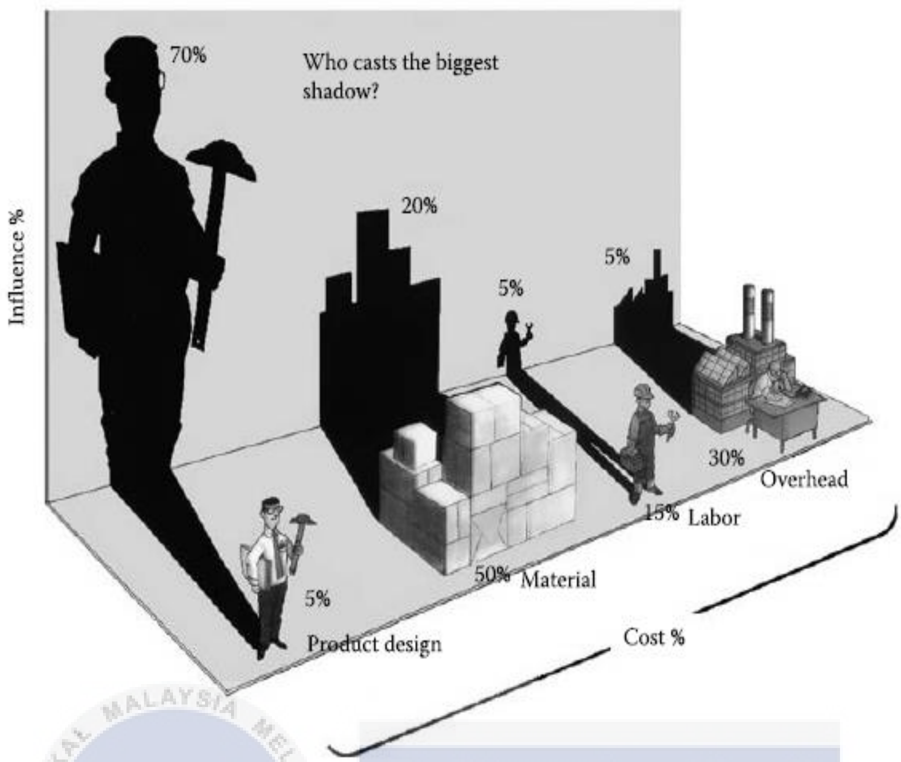


Figure 2.1: Who casts the biggest shadow? (Boothroyd, 2002)

In Figure 2.2, showing that the application of DFMA gives shorten percentage of design time to bring to market compared with traditional design process. Traditional design process is a process that divides in every single phase of development process. The development design process included engineering design, manufacturing, testing, marketing and production. The next phase can only proceed when the previous phase is completed. This process orderly step-by-step very slow and lead product lost sales in competitive market place.

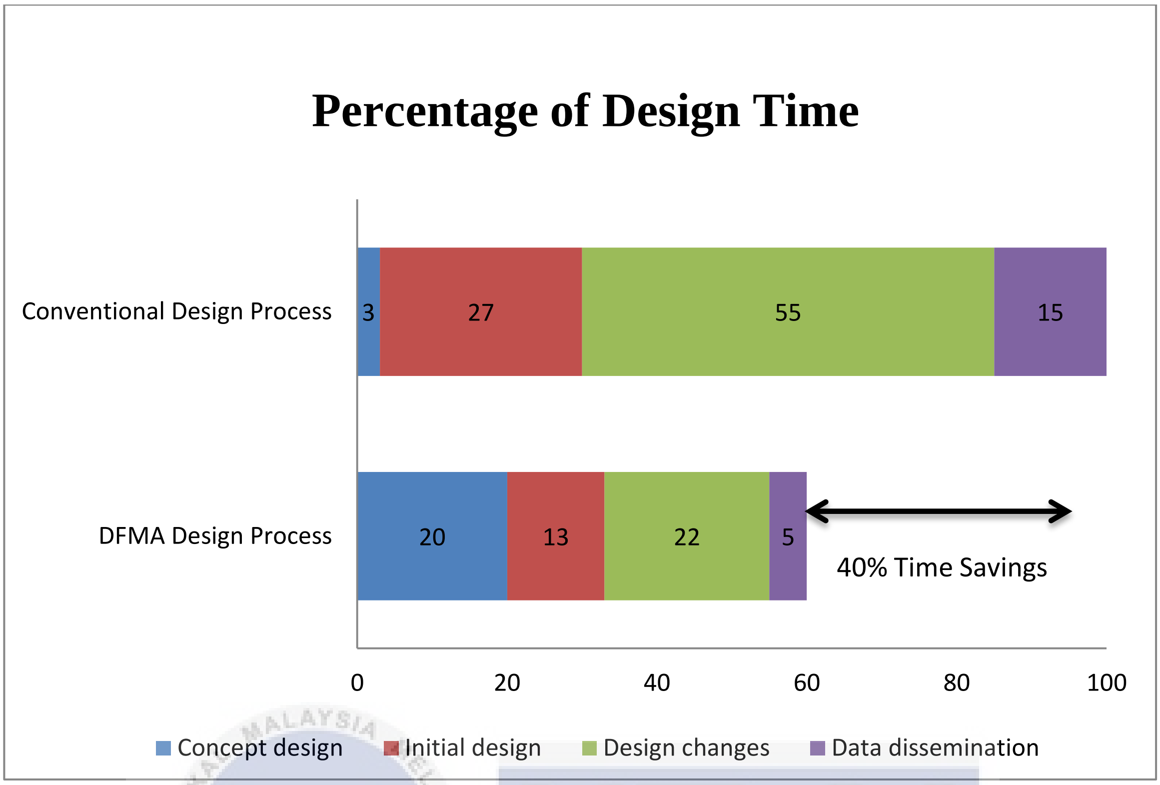


Figure 2.2: Time delivery comparison between DFMA and traditional design process (Boothroyd, 2002)

2.3 Design for Manufacture (DFM)

The term "design for manufacture" (DFM) means the product is designed for easy to manufacture of the group of parts after assembly (Boothroyd, 2002). Beside that, DFM also refers to design activity based on minimizing the production cost and time of the product to market at the same time maintaining the product quality (Mellvyne, 2007). There are five principles that designer need to consider:

i. Minimizing the part count

ii. Minimizing fastener

iii. Standardizing the manufacturing part

iv. Using unidirectional assembly

v. Correct assembly tolerances

DFM can be classified into several subdivisions (Boothroyd, 2002):

i. Design for Machining
ii. Design for Injection Molding
iii. Design for Sheet Metal Working
iv. Design for Die Casting
v. Design for Powder Metal Processing
vi. Design for Sand Casting
vii. Design for Investment Casting
viii. Design for Hot Forging

There are three goals in DFM:

i. Improve or increase the quality of new produces during the development period, including design, technology, manufacturing, service and so on.
ii. Reduce the manufacturing cost, including the cost design, technology, manufacturing, delivery, technical support, discarding and so on.
iii. Cut down the developing cycle time and production time, including the time of design, manufacturing preparing and repeatedly calculation.

2.3.1 DFM Guidelines

The main of any design for manufacturing system is a group of design principles or guidelines that are structured to help the designer reduce the cost. At the same time it also helps in reduce the difficulty of manufacturing an item. Following are the list of these guidelines:

1. **Reduce the total number of parts.**

By reducing of the number of parts in a product is probably the best opportunity for reducing manufacturing costs. Less parts implies less purchases, inventory, handling, processing time, development time, equipment, engineering time, assembly difficulty, service inspection, testing, etc. In general, it reduces the level of intensity of all activities related to the product during its entire life. A part that does not need to have relative motion with respect to other parts, does not have to be made of a different material, or that would make the assembly or service of other parts extremely difficult or impossible, is an excellent target for elimination. Some approaches to part-count reduction are based on the use of one-piece structures and selection of manufacturing processes such as injection molding, extrusion, precision castings, and powder metallurgy, among others.

2. **Develop a modular design.**

The use of modules in product design simplifies manufacturing activities such as inspection, testing, assembly, purchasing, redesign, maintenance, service, and so on. One reason is that modules add versatility to product update in the redesign process, help run tests before the final assembly is put together, and allow the use of standard components to minimize product variations. However, the connection can be a limiting factor when applying this rule.

3. **Use of standard components.**

Standard components are less expensive than custom-made items. The high availability of these components reduces product lead times. Also, their reliability factors are well ascertained. Furthermore, the use of standard components refers to the production pressure to the supplier, relieving in part the manufacture's concern of meeting production schedules.

4. **Design parts to be multi-functional.**

Multi-functional parts reduce the total number of parts in a design, thus, obtaining the benefits given in rule 1. Some examples are a part to act as both an electric conductor and as a structural member, or as a heat dissipating element and as a structural member. Also, there can be elements that besides their principal function have guiding, aligning, or self-fixturing features to facilitate assembly, and/or reflective surfaces to facilitate inspection, etc.

5. Design parts for multi-use.

In a manufacturing firm, different products can share parts that have been designed for multi-use. These parts can have the same or different functions when used in different products. In order to do this, it is necessary to identify the parts that are suitable for multi-use. For example, all the parts used in the firm (purchased or made) can be sorted into two groups: the first containing all the parts that are used commonly in all products. Then, part families are created by defining categories of similar parts in each group. The goal is to minimize the number of categories, the variations within the categories, and the number of design features within each variation. The result is a set of standard part families from which multi-use parts are created. After organizing all the parts into part families, the manufacturing processes are standardized for each part family. The production of a specific part belonging to a given part family would follow the manufacturing routing that has been setup for its family, skipping the operations that are not required for it. Furthermore, in design changes to existing products and especially in new product designs, the standard multi-use components should be used.

6. Design for ease of fabrication.

Select the optimum combination between the material and fabrication process to minimize the overall manufacturing cost. In general, final operations such as painting, polishing, finish machining, etc. should be avoided. Excessive tolerances, surface-finish requirement, and so on are commonly found problems that result in higher than necessary production cost.

7. **Avoid separate fasteners.**

The use of fasteners increases the cost of manufacturing a part due to the handling and feeding operations that have to be performed. Besides the high cost of the equipment required for them, these operations are not 100% successful, so they contribute to reducing the overall manufacturing efficiency. In general, fasteners should be avoided and replaced, for example, by using tabs or snap fits. If fasteners have to be used, then some guides should be followed for selecting them. Minimize the number, size, and variation used; also, utilize standard components whenever possible. Avoid screws that are too long, or too short, separate washers, tapped holes, and round heads and flatheads (not good for vacuum pickup). Self-tapping and chamfered screws are preferred because they improve placement success. Screws with vertical side heads should be selected vacuum pickup.

8. **Minimize assembly directions.**

All parts should be assembled from one direction. If possible, the best way to add parts is from above, in a vertical direction, parallel to the gravitational direction (downward). In this way, the effects of gravity help the assembly process, contrary to having to compensate for its effect when other directions are chosen.

9. **Maximize compliance.**

Errors can occur during insertion operations due to variations in part dimensions or on the accuracy of the positioning device used. This faulty behavior can cause damage to the part and/or to the equipment. For this reason, it is necessary to include compliance in the part design and in the assembly process. Examples of part built-in compliance features include tapers or chamfers and moderate radius sizes to facilitate insertion, and nonfunctional external elements to help detect hidden features. For the assembly process, selection of a rigid-base part, tactile sensing capabilities, and vision systems are example of compliance. A simple solution is to use high-quality parts with designed-in-compliance, a rigid-base part, and selective compliance in the assembly tool.

10. **Minimize handling.**

Handling consists of positioning, orienting, and fixing a part or component. To facilitate orientation, symmetrical parts should be used whenever possible. If it is not possible, then the asymmetry must be exaggerated to avoid failures. Use external guiding features to help the orientation of a part. The subsequent operations should be designed so that the orientation of the part is maintained. Also, magazines, tube feeders, part strips, and so on, should be used to keep this orientation between operations. Avoid using flexible parts - use slave circuit boards instead. If cables have to be used, then include a dummy connector to plug the cable (robotic assembly) so that it can be located easily. When designing the product, try to minimize the flow of material waste, parts, and so on, in the manufacturing operation; also, take packaging into account, select appropriate and safe packaging for the product.

2.4 Design for Assembly (DFA)

The aim of design for assembly (DFA) is to simplify the product so that the cost of assembly can be reduced. However, consequences of applying DFA usually include improved quality and reliability and a reduction in production equipment and part inventory. These secondary benefits often outweigh the cost reductions in assembly (Vincent Chan, Filippo A. Salustri, 2003).

DFA recognizes the need to analyze both the part design and the whole product for any assembly problems at early the design process. DFA defined as "*a process for improving product design for easy and low-cost assembly, focusing on functionality and on assemblability concurrently*." The primary criteria are considered in a DFA study as the following (Krumenauer, Matayoshi, Filho, Batalha & Engineering, 2008):

- Diminish and optimize part counts and types.
- Utilize optimum attachment methods
- Use layered assembly approach
- Reduce reorientations during assembly
- Minimize the need for adjustments
- Ensure the design parts are easy to self-align and locate
- Suitable access and unrestricted vision
- Confirm safety of part and assembly handling
- Installed correctly the design part
- Cut down the number of tools required

2.4.1 Manual Assembly

Manual assembly meant that human operator at a workstation reaches and grips a part from a plate then orients and located the part for insertion. Then, the operator will place the parts together and fastens them by power tool. The process of manual assembly process can be classified into two separate areas as part handling (acquiring, orienting, and moving the parts), and insertion and fastening (mating a part to another part or group of parts) (Boothroyd, 2002):

2.4.1.1 Part Handling

The part handling is considering acquiring, orienting and moving the parts. For ease of part handling, a designer should attempt to (Boothroyd, 2002):

i. Design parts that have an end-to-end symmetry and rotational symmetry about the axis of insertion. If this cannot be achieved, try to design parts having the maximum possible symmetry (refer Figure 2.3.a).

ii. Design parts that, in those instances where the part cannot be made symmetric, are obviously asymmetric (refer Figure 2.3.b).

iii. Provide features that prevent jamming of parts that tend to nest or stack when stored in bulk (refer Figure 2.3.c).

iv. Avoid features that allow tangling of parts when stored in bulk (refer Figure 2.3.d).

v. Avoid pars that stick together or are slippery, delicate, flexible, very small or very large, or that are hazardous to the handler (i.e., parts that are sharp, splinter easily, etc.) (refer Figure 2.4).

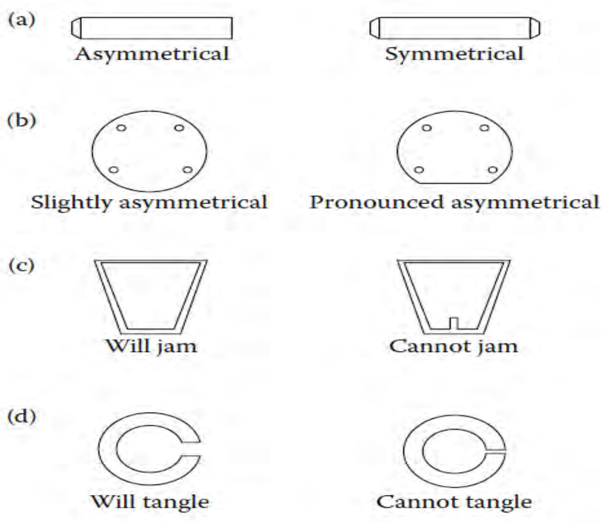


Figure 2.3: Geometrical features affecting part handling (Boothroyd, 2002)

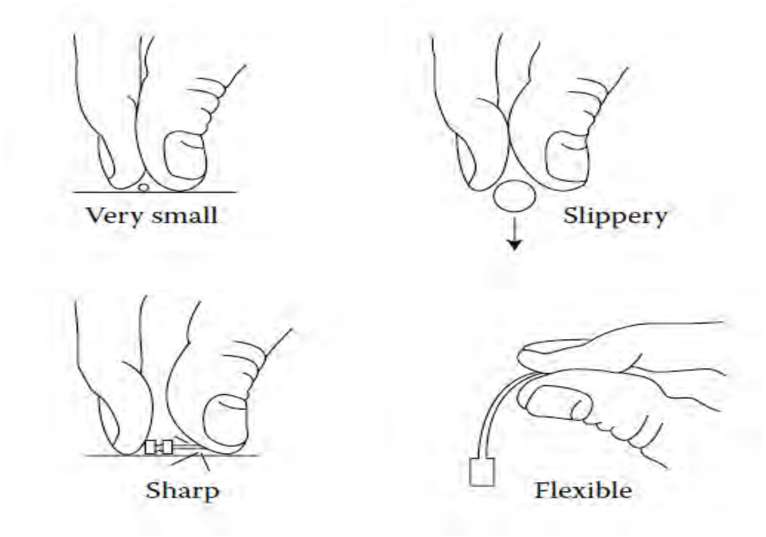


Figure 2.4: Some other features affecting part handling (Boothroyd, 2002)

2.4.1.2 Insertion and Fastening

The insertion and fastening is included mating a part to another part or group of parts. For ease of part handling, a designer should attempt to (Boothroyd, 2002):

i. Design so that there is little or no resistance to insertion and provide chamfers to guide the insertion of two mating parts. Generous clearance should be provided, but care must be taken to avoid clearances that result in a tendency for parts to jam or hang-up during insertion (refer Figures 2.5-2.8).

ii. Standardize by using common parts, processes, and methods across all models and even across product lines to permit the use of higher volume processes that normally result in lower product cost (refer Figure 2.9).

iii. 3. Use pyramid assembly—provide for progressive assembly about one axis of reference. In general, it is best to assemble from above (refer Figure 2.10).

iv. Avoid, where possible, the necessity for holding parts down to maintain their orientation during manipulation of the subassembly or during the placement of another part (refer Figure 2.11). If holding down is required, then try to design so that the part is secured as soon as possible after it has been inserted.

v. Design so that a part is located before it is released. A potential source of problems arises from a part being placed where, due to design constraints, it must be released before it is positively located in the assembly. Under these circumstances, reliance is placed on the trajectory of the part being sufficiently repeatable to locate it consistently (refer Figure 2.12).

vi. When common mechanical fasteners are used, the following sequence indicates the relative cost of different fastening processes, listed in the order of increasing manual assembly cost (refer Figure 2.13).

a. Snap fitting

b. Plastic bending

c. Riveting

d. Screw fastening

vii. Avoid the need to reposition the partially completed assembly in the fixture (refer Figure 2.14).

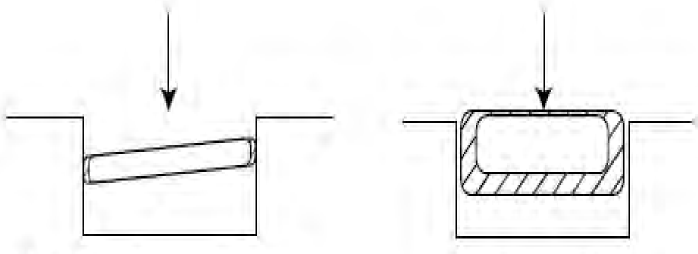


Figure 2.5: Incorrect geometry can allow a part to jam during insertion (Boothroyd, 2002)

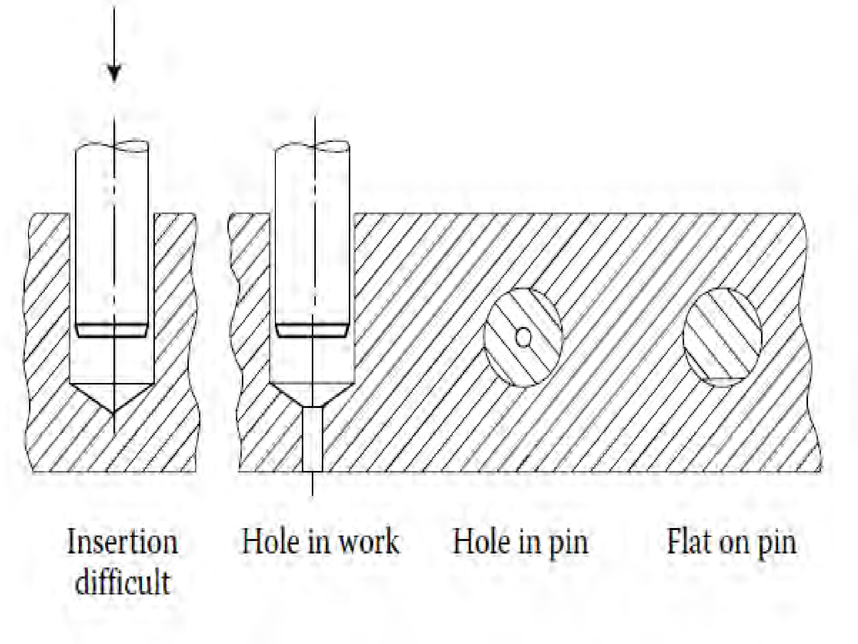


Figure 2.6: Provision of air-relief passages to improve insertion into blind holes (Boothroyd, 2002)

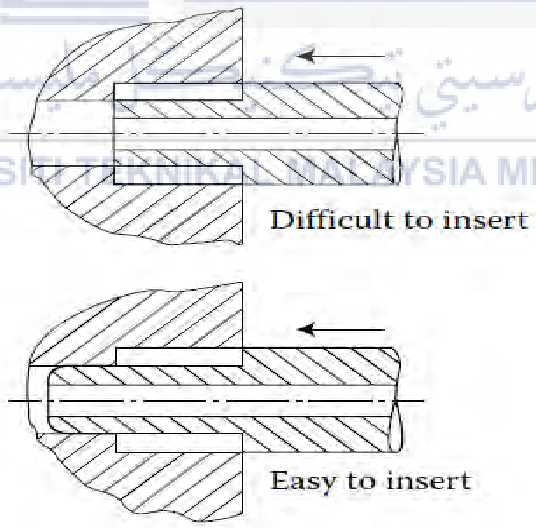


Figure 2.7: Design for ease of insertion—assembly of long-stepped bushing into counterbored hole (Boothroyd, 2002)

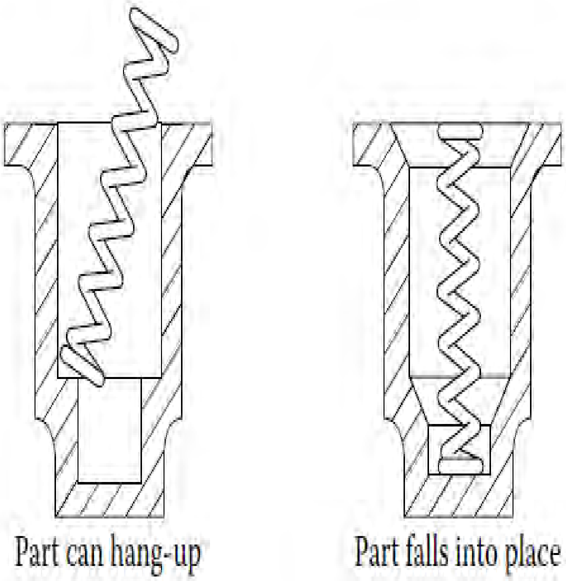


Figure 2.8: Provision of chamfers to allow easy insertion (Boothroyd, 2002)

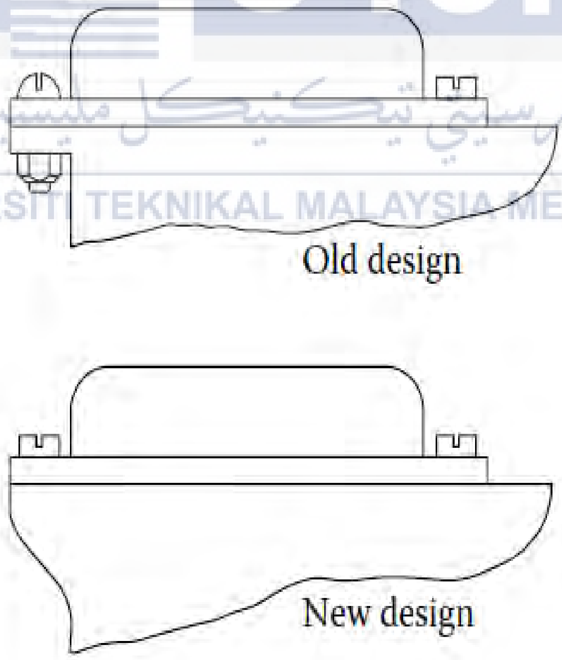


Figure 2.9: Standardize parts (Boothroyd, 2002)

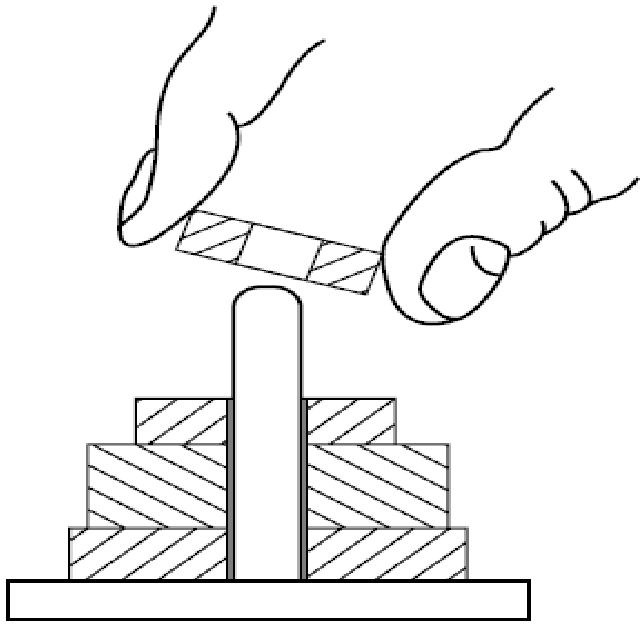


Figure 2.10: Provision of self-locating features to avoid holding down and alignment

(Boothroyd, 2002)

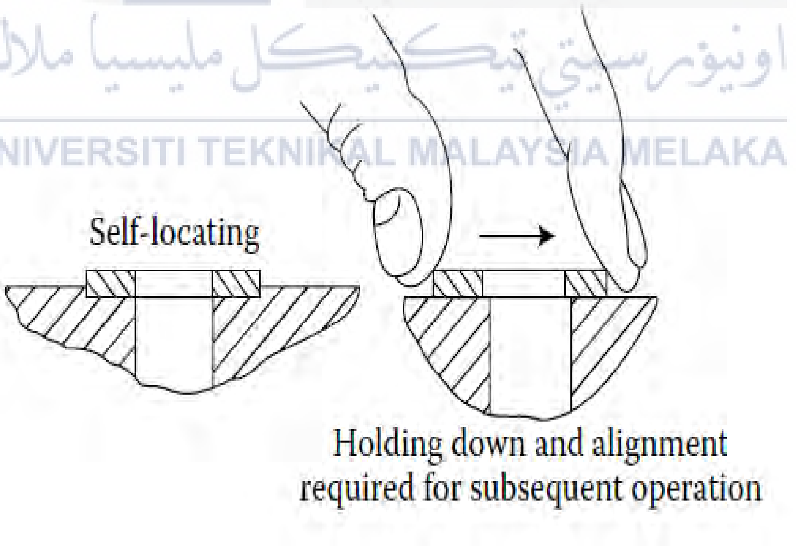


Figure 2.11: Provision of self-locating features to avoid holding down and alignment

(Boothroyd, 2002)

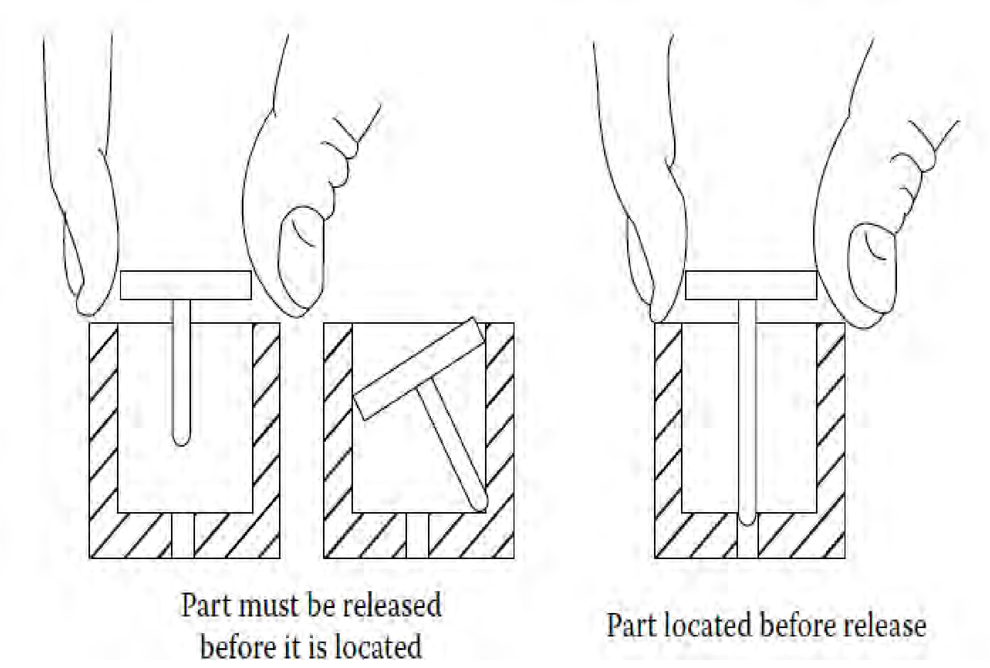


Figure 2.12: Design to aid insertion (Boothroyd, 2002)

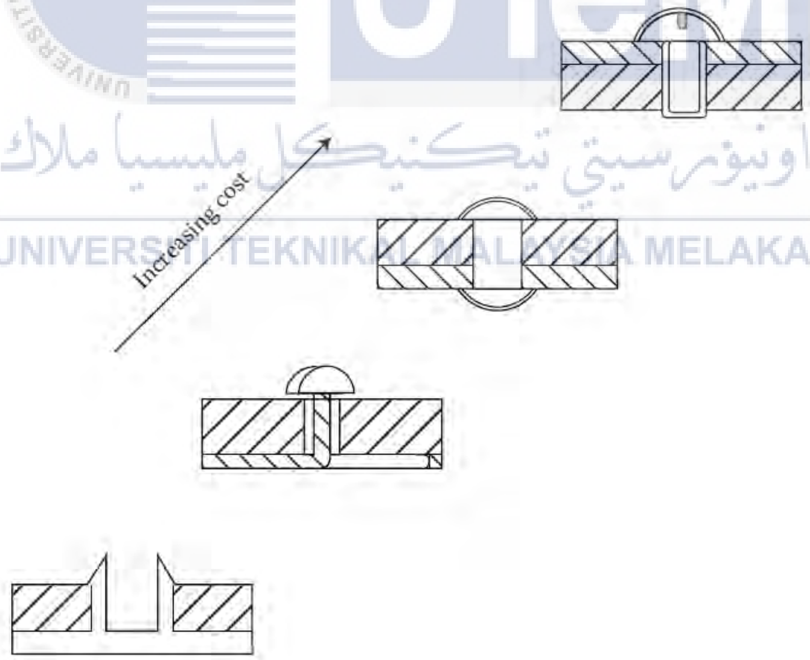


Figure 2.13: Common fastening methods (Boothroyd, 2002)

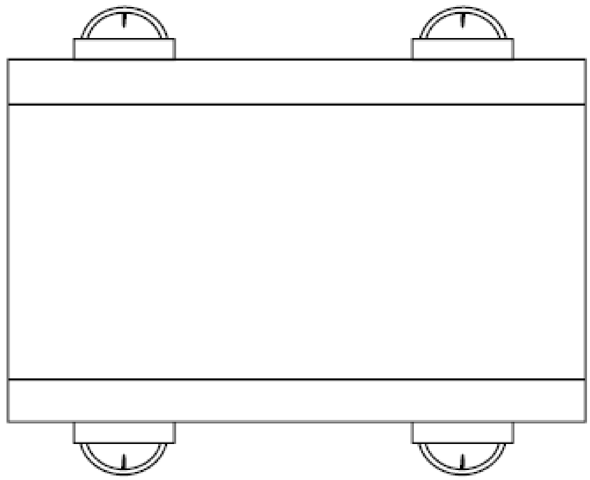


Figure 2.14: Insertion from opposite direction requires repositioning of the assembly (Boothroyd, 2002)

2.4.2 DFA Guidelines

The general guidelines of DFA is provided to the designer some guidance and simple rule when planning to design or creating a product. Following are the list of these guidelines:

- Reduce part count by combining multiple function into single parts
- Combine multiple parts into single subassemblies
- Assemble in open space and never conceal important components
- Classify the way to orient the part for insertion
- Use standardize part to minimize part variety
- Try to make the part symmetry
- Design in weight polar properties or geometric if there are non-symmetrical
- Abolish parts that tend to tangle
- Use color code to differentiate parts through shaped similarly
- Prevent nesting of parts

- Provide orientation features on non-symmetrical parts
- Design the mating feature for easy insertion
- Provide alignment features
- Abolish fasteners
- Place fastener away from obstructions
- Deep channels should be sufficiently wide to provide access to fastening tools
- Provision flats for fastening ease and uniform fastening
- Proper clearance ensures allowance for a fastening tool

2.4.3 Design Efficiency

An essential ingredient of the DFA method is the use of a measure of the DFA index or design efficiency of the proposed design. There are two factors that influence the assembly cost of a product or subassembly which are the number of the parts in a product and the ease of handling, insertion and fastening of the parts.

The DFA index is a figure obtained by dividing the theoretical minimum assembly time by the actual assembly time. The equation for calculating the DFA index $E_{ma}$is:

$$E_{ma} = \frac{N_{min} t_a}{t_{ma}} \tag{2.1}$$

where $N_{min}$is the theoretical minimum number of parts, t_a is the basic assembly time for one part and t_{ma} is the estimated time to complete the assembly of the product. The basic assembly time is the average time for a part that presents no handling, insertion or fastening difficulties (about 3s).

For theoretical minimum part count method, it does not take cost and time considerations. However it is can calculated the efficiency of the theoretical part count of the product as Eq. (2.2):

$$Theoretical\ part\ count\ efficiency = \frac{Number\ of\ theoretical\ count\ part}{Total\ number\ of\ parts} \times 100\% \quad (2.2)$$

For this purpose, the DFA method combines a system of estimating the total assembly time, operational cost and design efficiency to give the designer the information needed to undergo appropriate decision. The assembly time (TM) is calculated using Eq. (2.3), operation cost (TK) as Eq. (2.4) and design efficiency (DE) as Eq. (2.5):

$$TM = (Number\ of\ repetitions) \times (Handling\ time + Insertion\ time) \quad (2.3)$$

$$TK = \frac{Cost}{Second} \times TM \quad (2.4)$$

$$DE = \frac{3 \times Theoretical\ minimum\ part\ count}{TM} \quad (2.5)$$

2.5 Table Fan

A fan is a device used to induce airflow and generally made from broad, flat surfaces which revolve or oscillate. The most prevalent applications of fans are for creature comfort, ventilation, or gaseous convey for industrial purposes. The simplest kind of fans is leaves or flat objects, waved to engender a more comfortable atmosphere. Typical applications include decor, climate control, cooling systems, personal wind-generation (such as an electric table fan), ventilation (like an exhaust fan), winnowing (such as dissevering chaff of cereal grains), abstracting dust (like the sucking in a vacuum cleaner), drying (conventionally in addition to heat) and to provide draft for a fire. It is also commonly to utilize electric fans as air fresheners, by annexing fabric softener sheets to the protective housing. This causes the fragrance to be carried into the circumventing air.

Basic elements of a typical table fan include the fan blade, base, armature and lead wires, motor, blade sentinel, motor housing, oscillator gearbox, and oscillator shaft. The oscillator is a mechanism that forms of kineticism the fan from side to side. The axle emerges on both cessations of the motor, one terminus of the axle is annexed to the blade and the other is annexed to the oscillator gearbox. The motor case joins to the gearbox to contain the rotor and stator. The oscillator shaft cumulates to the weighted base and the gearbox. A motor housing covers the oscillator mechanism. The blade sentinel joins to the motor case for safety.

Among collectors, electro-mechanical fans are rated according to their condition, size, age, and number of blades. Three-blade designs are the most prevalent. Four-blade or five-blade designs are rarely used. The materials, from which the components are made, such as brass, are consequential factors in fan desirability (Anonymous, 2015).

2.6 DFMA: Case Studies

2.6.1 An Integrated DFMA-PDM Model for the Design and Analysis of Challenging Similar and Dissimilar Welds

In this study, an incipient design manufacturing and assembly (DFMA) model integrated with a product data management (PDM) system was developed in order to exploit the advantages of concurrent engineering (CE) in the design of welded structures. The model was constructed so that it enables the design of the weld as a separate design module simultaneously with other structural components and thus consistent with CE strategy. To facilitate decision-making, an application predicated cull method was introduced for determining congruous base materials, the welding process and filler metals. The usability of this approach was illustrated for cull of the base and filler metals for an Arctic application. For the concrete example considered in this work, the proposed model offers more facile and more expeditious cull of material and filler metals and enables designers to expeditiously evaluate different material and filler metal options. However, further studies are required to assess the efficacy and validity of the model for other applications in terms of cull of materials, welding processes and filler metals as well as design reliability and manufacturability (Tasalloti, H., Eskelinen, H., Kah, P., & Martikainen, J., 2015).

2.6.2 Software Development of Assembly Sequence Approach for Table Fan by Using Integrated Triz, Axiomatic Design and Boothroyd-Dewhurst DFA

Price is one of the consequential packages that must have in a product so it can be more competent in market. Assembly cost is one of the major operations in manufacturing but always ignored during designing stage. Design is a process that requires ingeniousness of an engineer. Theory Inventive Quandary Solving (TRIZ) and Axiomatic Design (AD) is a method which provides guidelines for the designer to design a product. This project is aim to utilize develop a software by utilizing the integrate approach of AD, TRIZ and DFMA to ameliorate product design process. The software was developed by utilizing Microsoft Visual Fundamental 6. The result of this research is software denominated Axiomatic-DFA. Comparative analysis will be done between current and proposed design. Utilizing integration of AD and TRIZ, current design is ameliorated in terms of Design for Assembly (DFA). Current components will be analyzed utilizing DFA method to ken the caliber of assembly efficacy. . The assembly efficacy of current design will obtain, and will be set a datum. Then, integration of AD and TRIZ are acclimated to engender the proposed design. A survey among possible customer is done and translates to the customer domain. Functional requisites are tenacious to satiate customer requisite. If FR identified doesn't meet the constrained or coupled, the process will perpetuated with TRIZ method .Using 3 TRIZ implements, the proposed design should be obtained in the cessation of the analysis. Proposed design is evaluated and culled predicated on Pugh method. DFA analysis of optimized design is done and comparative analysis is made between the current and proposed design. The final result of the project shows that design efficiency is incremented by 8.2 %.The develop software then checked for its validity in terms of its result by comparing to the genuine software that is in the market already the Boothroyd-Dewhurst DFA. The comparison shows that the incipiently-develop Axiomatic-DFA got a precision in the range of 94.6-99.4 % in terms of design efficiency (Tajul, 2008).

2.6.3 Design for Manufacturing and Assembly (DFMA) of Industry Product

The main purpose of the design for manufacturing and assembly is to simplify one product during manufacturing and assembly. The research of design for manufacturing and assembly (DFMA) has been undertaken a lot in the industrial field currently as it potential in reducing of total time in develops the product. The applications of design for manufacturing and assembly (DFMA) widely been explored and many potentials field has been discovered for its utilization. Boothroyd method is utilized to improve product design of a standing fan. The Boothroyd analysis concentrate on product handling and insertion until assembly is completely done. Analysis was done on each part to identify function, its strength and weakness of the product. After the design was amended on the analysis on the process and material cull was made. This is to ascertain the best material and the suitable processes. Through this method a few concepts have been developed and the best concept has been culled by considering the screening and scoring value. There were about 60 components in the old product and it was reduce to 33 components. This is reflected additionally in engenderment. The number of operator was reduced 11 to 6. The result from the analysis shows that efficiency of the design is ameliorated from 18 to 31 (Mohd Izwan, 2007).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter interpret about the methods and theories used to complete this project. Besides, this chapter also will described the products have been selected. The selected product will be disassemble to get the number of components and measured the dimension of the existing part of the products. The product will be analyzed using Boothroyd Dewhurst DFMA method. Boothroyd Dewhurst Manual Analysis and DFMA Software Analysis in DFA and DFM are necessary used in this project.

3.2 Project Flowchart

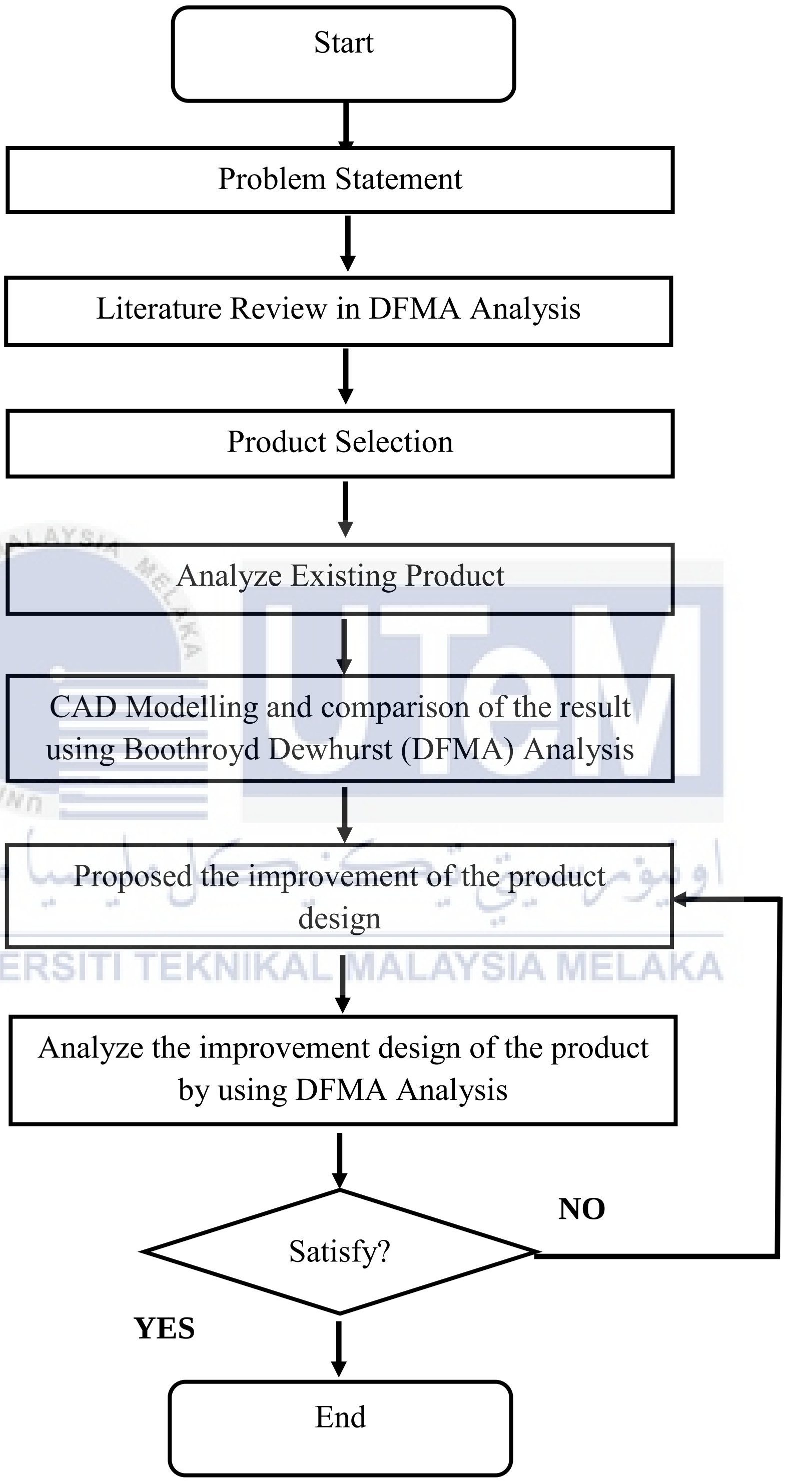


Figure 3.1: Project flowchart

3.3 Product Selection and Identification

In this research, two brands of electric table fan have been selected as case study to compare the design efficiency between this two difference brands of electric table fan. The two brands of table fan which are National and Pensonic. Table fan (National) is former brand used by Panasonic Corporation and made in Japan. Table fan (Pensonic) is product from company based in Malaysia. Both table fan is using 13A and 220-240V while the energy used for table fan (National) is 37W and for table fan (Pensonic) is 35W. These two table fans had the potential to be modified and redesign after applying the Design for Manufacturing and Assembly (DFMA) methodology.

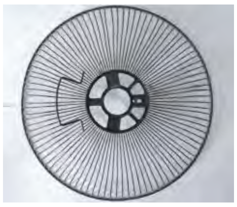
3.4 Product Disassembles

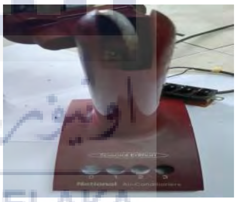
3.4.1 Bill of Materials (BOM) of Table fan (National)

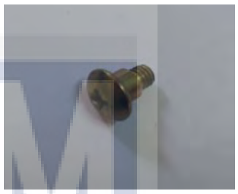
Table fan (National) contains 20 difference parts and total 29 components in this existing table fan. In Figure 3.2 show the image of table fan (National). The difference parts included front fan cover, rear fan cover, blade unit, rear plate fastener, threaded cap for blade, front motor cover, motor housing, lower part stand casing, fan head coupling, shaft, stand, switch, knob, bolts, nut, screw A, B, C and D. the bill of material (BOM) of table fan (National) is shown in Table 3.1.

Figure 3.2: Image of table fan (National)

Table 3.1: Bill of Material (BOM) of table fan (National)

NO	PART NAME	QUANTITY	DESCRIPTION	FIGURE
1	Front fan cover	1	Protects fan blade	
2	Rear fan cover	1	Protect fan blade	
3	Blade unit	1	Circulates air	
4	Rear plate fastener	1	Fasten rear plate	
5	Threaded cap for blade	1	Holds blade unit in place	
6	Front motor cover	1	Protect motor components	
7	Motor housing	1	Covers motor, shaft and electrical components	

8	Lower part stand casing	1	Protect circuit and switch	
9	Lower part stand casing	1	Protect circuit and switch	
10	Fan head coupling	1	Attaches fan head to stand	
11	Shaft	1	Transmits motor power to fan and oscillation gearing	
12	Stand	1	Hold fan head	
13	Switch	1	Selects speed of fan	
14	Knob	1	Control oscillation of fan	
15	Screw A	8	Fastens various parts together	

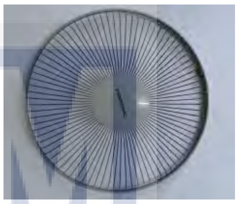
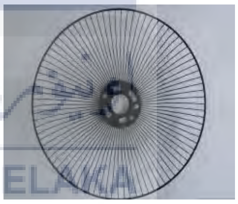
16	Screw B	1	Fastens various parts together	
17	Bolts	1	Fastens part using a nut	
18	Nut	1	Interfaces with bolt to fasten	
19	Screw C	2	Fastens various parts together	
20	Screw D	2	Fastens various parts together	

3.4.2 Bill of Materials (BOM) of Table fan (Pensonic)

Table fan (National) contains 18 difference parts and total 23 components in this existing table fan. In Figure 3.3 show the image of table fan (Pensonic). The difference parts included front fan cover, rear fan cover, blade unit, rear plate fastener, threaded cap for blade, front motor cover, motor housing, lower part stand casing, fan head coupling, shaft, stand, switch, knob, bolts, nut, screw A, B and C. The bill of material (BOM) of table fan (Pensonic) is shown in Table 3.2.

Figure 3.3: Image of table fan (Pensonic)

Table 3.2: Bill of Material (BOM) of table fan (Pensonic)

NO	PART NAME	QUANTITY	DESCRIPTION	FIGURE
1	Front fan cover	1	Protects fan blade	
2	Rear fan cover	1	Protect fan blade	
3	Blade unit	1	Circulates air	
4	Rear plate fastener	1	Fasten rear plate	

5	Threaded cap for blade	1	Holds blade unit in place	
6	Front motor cover	1	Protect motor components	
7	Motor housing	1	Covers motor, shaft and electrical components	
8	Lower part stand casing	1	Protect circuit and switch	
9	Fan head coupling	1	Attaches fan head to stand	
10	Shaft	1	Transmits motor power to fan and oscillation gearing	
11	Stand	1	Hold fan head	

12	Switch	1	Selects speed of fan	
13	Knob	1	Control oscillation of fan	
14	Screw A	5	Fastens various parts together	
15	Screw B	2	Fastens various parts together	
16	Bolts	1	Fastens part using a nut	
17	Nut	1	Interfaces with bolt to fasten	
18	Screw C	1	Fastens lower part casing and stand together	

3.5 CAD Modelling

Computer-aided design or CAD modelling is required used in this research. The CAD software that used in this research is CATIA V5R20 for the drawing process. The CATIA V5R20 was chosen because user can easily generate drawing 3-Dimensional from a model. The function of photorealistic rendering and animation is allowed user to communicate how future products will look and perform early in the development cycle.

The purpose of drawing of the existing table fan by using CATIA V5R20 is to obtain a great resource of information on how to improve the design of the current fable fan design. First, the existing table fan is dissembled and the dimension of the part is measured for the existing table fans. The detail drawings of each component will be drawn in CAD.

3.6 DFA Analysis for Existing Product

3.6.1 Theoretical Minimum Part

In order reducing the part count, the DFA methodology provides three criteria which each part must be examined as it added to the product during assembly. The three criteria are listed as below:

i. Does the part move relative to all other parts already assembled.
ii. Does the part must be a different material or be isolated from all other parts already assembled.
iii. Does the part must be separate from all other parts already assembled.

When the parts meet all the criteria, a theoretical minimum part count for the product is obtained. The part considered theoretically not necessary if the all three criteria not satisfied. However, theoretical minimum part count does not take considerations on cost and time but it is simply provides a basis measure of the design quality from an assembly viewpoint besides using DFA software. Figure 3.4 shows the steps to undergo the theoretical minimum part count for the product. After undergoes this step, the components can be identified the part as essential part (1) or non-essential (0).

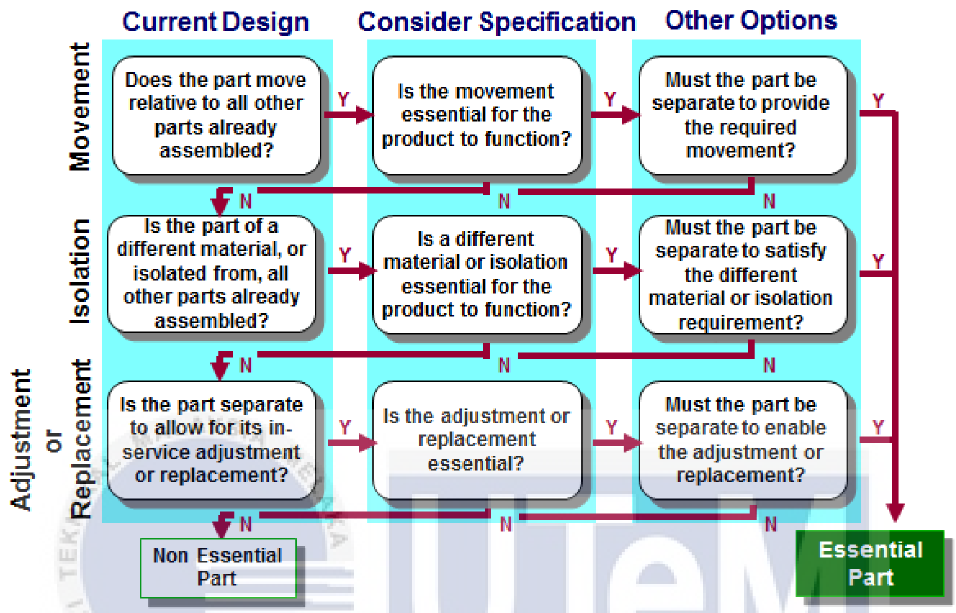
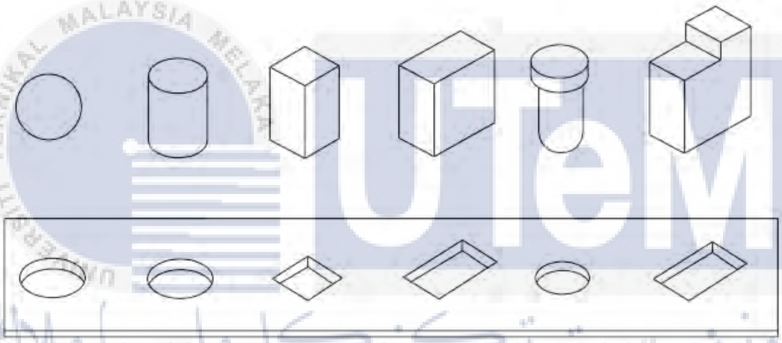


Figure 3.4: The steps of theoretical minimum part count ((Boothroyd Dewhurst,2002)

After undergo this step, the theoretical minimum part count efficiency of the product can be calculated by using Eq.(2.2) and design efficiency by using Eq.(2.3). The design efficiency is the total theoretical minimum part count multiple with the minimum time assembly for each part divided by total assembly time where get from the manual handling and insertion estimated time analysis and expressed it as a percentage. The minimum time assembly per part is assumed in 3s for an ideal design which meant the unwanted parts have been eliminated or combined with other parts and to make sure all the parts are easily to assemble.

3.6.2 Alpha and Beta Symmetry

The orientation involves a proper alignment of the part to be inserted of the parts needs to be considered the axis of insertion and rotation. Alpha (α) symmetry depends on the angle through which a part must be rotated about an axis perpendicular to the axis of insertion to repeat its orientation. Meanwhile for Beta (β) symmetry depends on the angle through which a part must be rotated about the axis of insertion to repeat its orientation. Then the part's Alpha and Beta rotational symmetries are determined by referring Figure 3.5.



α	0	180	180	90	360	360
β	0	0	90	180	0	360

Figure 3.5: Alpha and Beta rotational symmetries for various parts (Boothroyd Dewhurst,2002)

3.6.3 Classification Systems

The classification systems is an assembly processes which the systematic arrangement of part features that affect the acquisition, movement, orientation, insertion and fastening of the part together with some operations that are not associated with specific parts such as turning assembly over (Boothroyd, 2002). In order to get complete classification system, the corresponding time standards is determined which are manual handling-estimated times and manual insertion-estimated times as presented in Table 3.3 and Table 3.4.

It can be seen the classification numbers consists of two digits. The first digit represents the row and the second digit represents the column in the tables. The manual insertion and fastening process is concerned with the interaction between each part as they are assembled. Manual insertion and fastening consists a finite variety of basic assembly task such as screw, weld, peg-in-hole, rivet, press-fit, etc. that are common to most manufactured products.

Following are definitions for manual handling-estimated time as represented in Table 3.3 (Boothroyd, 2002):

i. Alpha: the rotational symmetry of the part about perpendicular axis to its axis of insertion. For parts with an axis of insertion, end-to-end orientation is necessary when alpha equals 360°, otherwise alpha equals 180°.
ii. Beta: the rotational symmetry of the part about its axis of insertion. The magnitude of rotational symmetry is the smallest angle through which the part can be rotated and repeated its orientation.
iii. Thickness: the length of the shortest side of the smallest rectangular prism that enclosed the part.
iv. Size: the length of the shortest side of the smallest rectangular prism that can enclose the part.

Following are definitions for manual insertion-estimated time as represented in Table 3.4 (Boothroyd, 2002):

i. Holding down required: the part require gripping, realignment or holding down before it is finally secured.

ii. Easy to align and position: the insertion is facilitated by well-designed chamfers or similar features.

iii. Obstructed access: the space available for the assembly operation causes a significant increase in the assembly time.

iv. Restricted vision: the operator has to rely mainly on tactile sensing during the assembly process.

Table 3.3: Original classification system for part features affecting manual handling time

(Boothroyd Dewhurst,2002)

MANUAL INSERTION-ESTIMATED TIMES (s)

Key: Part added but not secured

		After assembly no holding down required to maintain orientation and location (3)				Holding down required during subsequent processes to maintain orientation at location (3)			
		Easy to align and position during assembly (4)		Not easy to align or position during assembly		Easy to align and position during assembly (4)		Not easy to align or position during assembly	
		No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)
		0	1	2	3	6	7	8	9
Addition of any part (1) where neither the part itself nor any other part is finally secured immediately: Part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Key: Part secured immediately

		No screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		Plastic deformation immediately after insertion						Screw tightening immediately after insertion	
				Plastic bending or torsion			Riveting or similar operation				
					Not easy to align or position during assembly			Not easy to align or position during assembly			
		Easy to align and position with no resistance to insertion (4)	Not easy to align or position during assembly and/or resistance to insertion (5)	Easy to align and position during assembly (4)	No resistance to insertion	Resistance to insertion (5)	Easy to align and position during assembly (4)	No resistance to insertion	Resistance to insertion (5)	Easy to align and position with no torsional resistance (4)	Not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
Addition of any part (1) where the part itself and/or other parts are being finally secured immediately: Part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
Part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: Due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
Part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: Due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

Key: Separate operation

		Mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-fastening processes	
		None or localized plastic deformation				Metallurgical processes					
							Additional material required				
		Bending or similar process	Riveting or similar processes	Screw tightening or other processes	Bulk plastic deformation (large proportion of part is plastically deformed during fastening)	No additional material required (e.g. resistance, friction welding, etc.)	Soldering processes	Weld/braze processes	Chemical processes (e.g. adhesive bonding, etc.)	Manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	Other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	8
Assembly processes where all solid parts are in place	9	4	7	5	12	7	8	12	12	9	12

Table 3.4: Original classification system for part features affecting insertion and fastening

(Boothroyd Dewhurst,2002)

MANUAL INSERTION-ESTIMATED TIMES (s)

Key:

- Part added but not secured

		After assembly no holding down required to maintain orientation and location (3)				Holding down required during subsequent processes to maintain orientation at location (3)			
		Easy to align and position during assembly (4)		Not easy to align or position during assembly		Easy to align and position during assembly (4)		Not easy to align or position during assembly	
		No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)
		0	1	2	3	6	7	8	9
Addition of any part (1) where neither the part itself nor any other part is finally secured immediately: Part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

- Part secured immediately

		No screwing operation or plastic deformation immediately after insertion (snap/press fits,circlips,spire nuts,etc.)		Plastic deformation immediately after insertion						Screw tightening immediately after insertion	
				Plastic bending or torsion			Riveting or similar operation				
					Not easy to align or position during assembly			Not easy to align or position during assembly			
		Easy to align and position with no resistance to insertion (4)	Not easy to align or position during assembly and/or resistance to insertion (5)	Easy to align and position during assembly (4)	No resistance to insertion	Resistance to insertion (5)	Easy to align and position during assembly (4)	No resistance to insertion	Resistance to insertion (5)	Easy to align and position with no torsional resistance (4)	Not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
Addition of any part (1) where the part itself and/or other parts are being finally secured immediately: Part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
Part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: Due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
Part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: Due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

- Separate operation

		Mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-fastening processes	
		None or localized plastic deformation				Metallurgical processes					
							Additional material required				
		Bending or similar process	Riveting or similar processes	Screw tightening or other processes	Bulk plastic deformation (large proportion of part is plastically deformed during fastening)	No additional material required (e.g. resistance, friction welding, etc.)	Soldering processes	Weld/braze processes	Chemical processes (e.g. adhesive bonding, etc.)	Manipulation of parts or sub-assembly (e.g. orienting, fittings or adjustment of part(s), etc.)	Other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	8
Assembly processes where all solid parts are in place	9	4	7	5	12	7	8	12	12	9	12

3.6.4 Design Efficiency of Product

Design efficiency is important in order to know the efficiency of the product. This process will determine after obtain the detail design like 3D modelling for the existing part. Each part of the product will be analysis as represented in Table 3.4. The design for manual assembly analysis worksheet is needed to record down all the information such as total angle of symmetry, manual handling code, handling time per second, manual insertion code, insertion time per item, total operation time and figures for minimum parts. This information can be obtained by referring Table 3.3 and 3.4. After gathering up all the information of the product, the design efficiency can be calculated and get the percentage of the design efficiency by using Eq.2.

Table 3.5: Design for manual assembly worksheet

No.	Item name	Number of items	Total angle of symmetry ($\alpha+\beta$), °	Manual handling code	Handling time per item, s	Manual insertion code	Insertion time per item, s	Total operation time, s	Figures for min. parts
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
							Total	TM	NM
							Design Efficiency		

3.6 New Concept Design Evaluation

The new concept design is proposed based on the improvement of the existing product design from the two different brands of table fan. After that, new conceptual design of new table fan is come out. In order to mesh the design characteristics, the design must be easily to assemble and reliability of the product by follows the scope and objective of the project. After done the sketching the proposed design, the bill of material (BOM) of the new table fan is needed to list out and the image of the conceptual design is figure out. The exploded 3D modelling view is process by using CATIA V5R20 and it is important to show out the fully design of the table fan.

3.7 Analysis of New Conceptual Design

After done the 3D modelling, this project will continued by undergoes the manual Boothroyd Dewhurst DFA analysis. For manual Boothroyd Dewhurst DFA analysis, the new conceptual table fan design is needed to carry out the number of theoretical minimum part count. The Alpha and Beta symmetry value need to identify by using same method of analysis Alpha and Beta symmetry of the existing product. After done the analysis, every part can be get the estimated insertion time, estimated handling time and manual handling and insertion code by referring Table 3.3 and Table 3.4.

After gathering up all the information, the manual assembly design worksheet is filling up to get the design efficiency and its percentage for new conceptual design of table fan. The manual assembly design worksheet that used is same as Table 3.5.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Background

In this chapter, the two different brands of existing products are analyzed by using manual Design for Manufacturing and Assembly (DFMA) method. The implementation of the modifications of the product will be proposed based on the existing products in term of the design efficiency. Besides, the drafting of new conceptual design and its detail drawing are proposed by using hand sketching and CATIA V5R20 software. The design efficiency of new conceptual design is analyzed by using manual Boothroyd Dewhurst (DFMA) method.

4.2 Analysis of the Existing Product

4.2.1 Theoretical Minimum Part of Table Fan (National)

In theoretical minimum part count, there are three elements needed to be considered which are movement, isolation and material. The theoretical minimum part count of the product is obtained when the part is satisfying the three elements. If either one of the criteria is satisfied, it is consider as theoretical minimum part count. Meanwhile if the part not satisfied all the three criteria then the part cannot be considered theoretically necessary. However, theoretical minimum part count is concerned about the number of essential of the product and no cost and time considerations. It is important element when calculating the design efficiency of the product. In Table 4.1 is showed the theoretical minimum part count of the table fan (National). In DFMA analysis, there are 10 essential theoretical parts of the table fan (National).

Table 4.1: Theoretical minimum part count of table fan (National)

No	Part Name	Movement	Isolation	Material	Theoretical Part	Justification
1	Front fan cover	No	Yes	No	✓	Front fan cover need to isolated in order to assemble blade unit easier.
2	Rear fan cover	No	Yes	No	✓	Rear fan cover need to isolated in order to assemble blade unit easier.
3	Blade unit	Yes	Yes	Yes	✓	This component operates as a rotating part so it is an essential part.
4	Rear plate fastener	No	No	No	X	Unnecessary due it can be combined as one part with other part.
5	Threaded cap for blade	No	No	No	X	This part can combined as a part with blade unit.
6	Front motor cover	No	Yes	No	✓	Necessary since it need to protect motor from touced the unit blade.

7	Motor housing	No	Yes	No	✓	It is no movement to occur but it need to assemble with other part.
8	Lower part stand casing	No	No	No	X	This part can be eliminate and combined with stand.
9	Lower part stand casing	No	No	No	X	This part can be eliminate and combined with stand.
10	Fan head coupling	Yes	Yes	No	✓	Since it need to support the head of fan for movement,thus it necessary part.
11	Shaft	Yes	Yes	No	✓	Necessary since to rotated the unit blade.
12	Stand	No	Yes	Yes	✓	The main part to support fan to stand.
13	Switch	Yes	Yes	Yes	✓	Necessary since it need to change the speed of fan.
14	Knob	Yes	Yes	No	✓	This part is rotating part and need for adjust the angle of fan.
15	Screw A	No	No	No	X	The screw can be eliminated by

						replaced from other type of assembly.
16	Screw B	No	No	No	X	The screw can be eliminated by replaced from other type of assembly.
17	Bolts	No	No	No	X	The bolts can be eliminated by replaced from other type of assembly.
18	Nut	No	No	No	X	The nut can be eliminated by replaced from other type of assembly.
19	Screw C	No	No	No	X	The screw can be eliminated by replaced from other type of assembly.
20	Screw D	No	No	No	X	The screw can be eliminated by replaced from other type of assembly.

4.2.2 Theoretical Minimum Part of Table Fan (Pensonic)

For table fan (Pensonic) is also need to undergo the theoretical minimum part count process as table fan (National). In Table 4.2 is showed the theoretical minimum part count of the table fan (Pensonic). In DFMA analysis, there are 10 essential theoretical parts of the table fan (Pensonic).

Table 4.2: Theoretical minimum part count of table fan (Pensonic)

No	Part Name	Movement	Isolation	Material	Theoretical Part	Justification
1	Front fan cover	No	Yes	No	✓	Front fan cover need to isolated in order to assemble blade unit easier.
2	Rear fan cover	No	Yes	No	✓	Rear fan cover need to isolated in order to assemble blade unit easier.
3	Blade unit	Yes	Yes	Yes	✓	Operates as a rotating part so it is an essential part.
4	Rear plate fastener	No	No	No	X	Unnecessary due it can be combined as one part with other part.
5	Threaded cap for blade	No	No	No	X	This part can combined as a part with blade

						unit.
6	Front motor cover	No	Yes	No	✓	Necessary since it need to protect motor from touced the unit blade.
7	Motor housing	No	Yes	No	✓	It is no movement to occur but it need to assemble with other part.
8	Lower part stand casing	No	No	No	X	This part can be eliminate and combined with stand.
9	Fan head coupling	Yes	Yes	No	✓	Since it need to support the head of fan for movement,thus it necessary part.
10	Shaft	Yes	Yes	No	✓	Necessary since to rotated the unit blade.
11	Stand	No	Yes	Yes	✓	The main part to support fan to stand.
12	Switch	Yes	Yes	Yes	✓	Necessary since it need to change the speed of fan.
13	Knob	Yes	Yes	No	✓	This part is rotating part and need for adjust the angle of fan.

14	Screw A	No	No	No	X	The screw can be eliminated by replaced from other type of assembly.
15	Screw B	No	No	No	X	The screw can be eliminated by replaced from other type of assembly.
16	Bolts	No	No	No	X	The bolts can be eliminated by replaced from other type of assembly.
17	Nut	No	No	No	X	The nut can be eliminated by replaced from other type of assembly.
18	Screw C	No	No	No	X	The screw can be eliminated by replaced from other type of assembly.

4.2.3 Alpha and Beta of Table Fan (National)

The detail result of the Alpha and Beta symmetric of each part of the table fan (National) is shown in Table 4.3.

Table 4.3: Alpha and Beta symmetric of table fan (National)

NO	PART NAME	FIGURE	Alpha (α)	Beta (β)
1	Front fan cover		0	360
2	Rear fan cover		360	360
3	Blade unit		0	180
4	Rear plate fastener		0	360
5	Threaded cap for blade		0	360

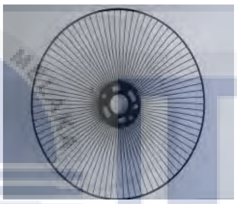
6	Front motor cover		360	360
7	Motor housing		360	360
8	Lower part stand casing		360	360
9	Lower part stand casing		360	360
10	Fan head coupling		360	360
11	Shaft		0	360
12	Stand		0	0

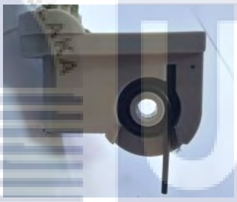
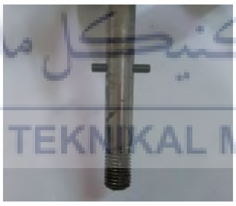
13	Switch		360	180
14	Knob		360	0
15	Screw A		360	0
16	Screw B		360	0
17	Bolts		360	0
18	Nut		180	0
19	Screw C		360	0
20	Screw D		360	0

4.2.4 Alpha and Beta of Table Fan (Pensonic)

The detail result of the Alpha and Beta symmetric of each part of the table fan (Pensonic) is shown in Table 4.4.

Table 4.4: Alpha and Beta symmetric of table fan (Pensonic)

NO	PART NAME	FIGURE	Alpha (α)	Beta (β)
1	Front fan cover		0	360
2	Rear fan cover		360	360
3	Blade unit		0	360
4	Rear plate fastener		0	360
5	Threaded cap for blade		0	360

6	Front motor cover		360	360
7	Motor housing		360	360
8	Lower part stand casing		360	360
9	Fan head coupling		360	360
10	Shaft		0	360
11	Stand		0	0
12	Switch		360	180

13	Knob		360	0
14	Screw A		360	0
15	Screw B		360	0
16	Bolts		360	0
17	Nut		180	0
18	Screw C		360	0

4.2.5 Design Efficiency of Table Fan (National)

Table 4.5 Design efficiency of table fan (National)

No.	Item name	Number of items	Total angle of symmetry (α+β), °	Manual handling code	Handling time per item, s	Manual insertion code	Insertion time per item, s	Total operation time, s	Figures for min. parts
1	Front fan cover	1	360	10	1.5	06	5.5	7.0	1
2	Rear fan cover	1	720	30	1.95	06	5.5	7.45	1
3	Blade unit	1	180	00	1.13	00	1.5	2.28	1
4	Rear plate fastener	1	360	10	1.5	00	1.5	3.0	0
5	Threaded cap for blade	1	360	10	1.5	00	1.5	3.0	0
6	Front motor cover	1	720	30	1.95	06	5.5	7.45	1
7	Motor housing	1	720	30	1.95	02	2.5	4.45	1
8	Lower part stand casing	1	720	30	1.95	00	1.5	3.45	0
9	Lower part stand casing	1	720	30	1.95	00	1.5	3.45	0
10	Fan head coupling	1	720	30	1.95	07	6.5	8.45	1
11	Shaft	1	360	10	1.5	39	8.0	9.5	1
12	Stand	1	0	00	1.13	00	1.5	2.63	1
13	Switch	1	540	20	1.8	06	5.5	7.3	1

14	Knob	1	360	10	1.5	01	2.5	4.0	1
15	Screw A	8	360	60	4.8	49	10.5	122.4	0
16	Screw B	1	360	60	4.8	49	10.5	15.3	0
17	Bolts	1	360	60	4.8	38	6.0	10.8	0
18	Nut	1	180	40	3.6	30	2.0	5.6	0
19	Screw C	2	360	60	4.8	49	10.5	30.6	0
20	Screw D	2	360	60	4.8	49	10.5	30.6	0
							Total	TM	NM
								288.71	10
							Design Efficiency	0.1039	

In Table 4.5 showed the result of design efficiency of table fan (National). For table fan (National), it has 20 difference parts and total 29 components that include the repeated part in this existing table fan. The assembly time of each part is refer in Table 3.3 of original classification system for part features affecting manual handling time and Table 3.4 of original classification system for part features affecting insertion and fastening. For the theoretical minimum part, the components can be defines as essential part (1) or non-essential part (0) based on Table 4.1.

There are the steps that need to undergo in order to get the operation time for stand of table fan in the assembly process. For Alpha (α) and Beta (β) analysis, it can be refer on Table 4. The stand is acts as base part due to stand is located at the bottom of the design and most of the part supported by fan stand. The total angle of symmetry of stand is 0°. From Table 3.3 and Table 3.4, the manual handling and insertion code of the stand can be identified which is 00. Therefore the handling time per item is 1.13s and for insertion time per item is 1.5s. The total operation assembly time for stand is 2.63s. For differences components have differences operation assembly time which is depend on its total angle of symmetry, component handling and insertion difficulties and repetition of the components.

Based on the analysis, the design efficiency of the product for National is 10.39%. The total operation is 288.71s and it has 10 theoretical minimum parts. The formula of design efficiency can be refer on Eq.(2.5). Following is the calculation of design efficiency for table fan (National):

$$\textbf{Design Efficiency} = \frac{\mathbf{3 \times NM}}{\mathbf{TM}}$$

$$= \frac{\mathbf{3 \times 10}}{\mathbf{288.71}}$$

$$= \mathbf{0.1039 \text{ or } 10.39\%}$$

4.2.6 Design Efficiency of Table Fan (Pensonic)

Table 4.6 Design efficiency of table fan (Pensonic)

No.	Item name	Number of items	Total angle of symmetry (α+β), °	Manual handling code	Handling time per item, s	Manual insertion code	Insertion time per item, s	Total operation time, s	Figures for min. parts
1	Front fan cover	1	360	10	1.5	06	5.5	7.0	1
2	Rear fan cover	1	720	30	1.95	06	5.5	7.45	1
3	Blade unit	1	360	00	1.13	00	1.5	2.28	1
4	Rear plate fastener	1	360	10	1.5	00	1.5	3.0	0
5	Threaded cap for blade	1	360	10	1.5	00	1.5	3.0	0
6	Front motor cover	1	720	30	1.95	06	5.5	7.45	1

7	Motor housing	1	720	30	1.95	02	2.5	4.45	1
8	Lower part stand casing	1	720	30	1.95	00	1.5	3.45	0
9	Fan head coupling	1	720	30	1.95	07	6.5	8.45	1
10	Shaft	1	360	10	1.5	39	8.0	9.5	1
11	Stand	1	0	00	1.13	00	1.5	2.63	1
12	Switch	1	540	20	1.8	06	5.5	7.3	1
13	Knob	1	360	10	1.5	01	2.5	4.0	1
14	Screw A	6	360	60	4.8	49	10.5	91.5	0
15	Screw B	5	360	60	4.8	49	10.5	76.5	0
16	Bolts	1	360	60	4.8	38	6.0	10.8	0
17	Nut	1	180	40	3.6	30	2.0	5.6	0
18	Screw C	1	360	60	4.8	49	10.5	15.3	0
							Total	TM	NM
								269.66	10
							Design Efficiency	0.1112	

For table fan (Pensonic), it undergoes same step as analysis on table fan (National). Based on the analysis, the design efficiency of the product for National is 11.12%. The total operation is 269.66s and it has 10 theoretical minimum parts. The formula of design efficiency can be refer on Eq.(2.5). Following is the calculation of design efficiency for table fan (National):

$$\textbf{Design Efficiency} = \frac{\mathbf{3 \times NM}}{\mathbf{TM}}$$

$$= \frac{\mathbf{3 \times 10}}{\mathbf{269.99}}$$

$$= \mathbf{0.1112 \text{ or } 11.12\%}$$

4.2.7 Comparison between Two Difference Brands of Products

This project is to evaluate and compare the design efficiency of different brands of table fan that served same function. The analysis result as shown in Table 4.5 and Table 4.6 indicated that the design efficiency of table fan (Pensonic) is higher than table fan (National). The first comparison will be in term of the parts number used in assembly. The table fan (National) design contains total 20 parts while for the table fan (Pensonic) have total 18 parts. The number of parts contains obviously effect the design efficiency of the product. Both table fan design also contains 10 theoretical minimum parts which is knob, front motor cover, motor housing, front fan cover, rear fan cover, blade unit, fan head coupling, shaft, stand and switch.

The design efficiency of table fan (National) is 10.39% and the table fan (Pensonic) has design efficiency of 11.12%. This clearly shows that the table fan (Pensonic) is much easier to be assembled compared to brand National. As the results obtained, the table fan (Pensonic) is much superior to the table fan (National) in term of assembly operation and design efficiency.

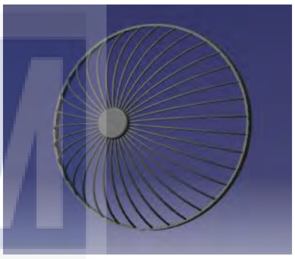
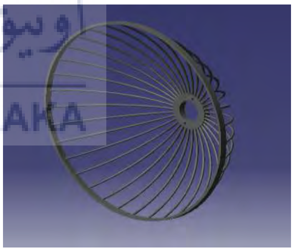
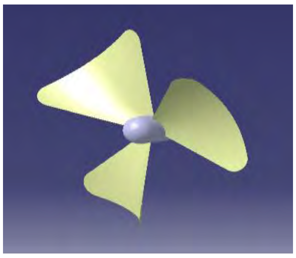
4.3 New Conceptual Design

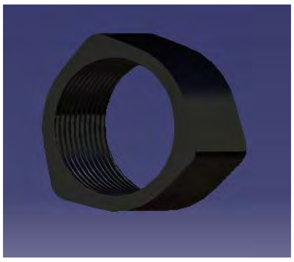
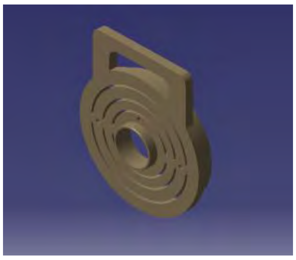
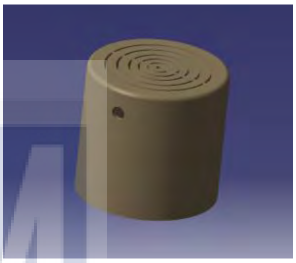
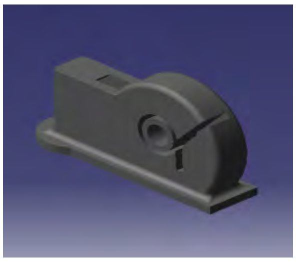
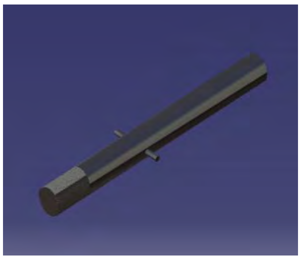
The implementation of the modification is proposed in order to improve the design of table fan. Based on DFMA analysis, some of the components can be eliminated and some modifications also suggested and applied for other components. The modification proposal was to eliminate the few screws, threaded cap for blade and lower part stand casing. For the blade and threaded cap for blade can be combined into one component for unnecessary feature. Rather using several types of screw, chassis and a snap method were used.

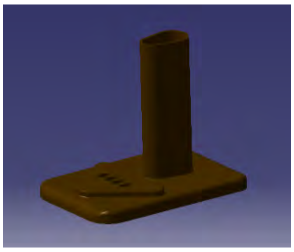
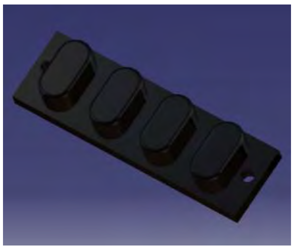
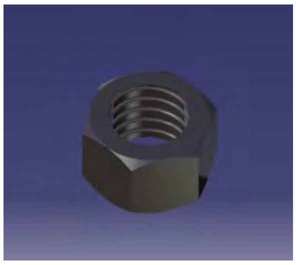
4.3.1 Bill of Materials (BOM) New Design of Table Fan

The new table fan contains 15 difference parts and totals 23 components in this improvement design. The 15 differences parts included front fan cover, rear fan cover, blade unit, rear plate fastener, front motor cover, motor housing, lower part stand casing, fan head coupling, shaft, stand, switch, knob, screw, bolt and nut. The bill of materials (BOM) of new design of table fan is shown in Table 4.7.

Table 4.7: Bill of Material (BOM) for new design of table fan

NO	PART NAME	QUANTITY	DESCRIPTION	FIGURE
1	Front fan cover	1	Protects fan blade	
2	Rear fan cover	1	Protect fan blade	
3	Blade unit	1	Circulates air	

4	Rear plate fastener	1	Fasten rear plate	
5	Front motor cover	1	Protect motor components	
6	Motor housing	1	Covers motor, shaft and electrical components	
7	Lower part stand casing	1	Protect circuit and switch	
8	Fan head coupling	1	Attaches fan head to stand	
9	Shaft	1	Transmits motor power to fan and oscillation gearing	

10	Stand	1	Hold fan head	
11	Switch	1	Selects speed of fan	
12	Knob	1	Control oscillation of fan	
13	Screw	9	Fastens various parts together	
14	Bolt	1	Fastens part using a nut	
15	Nut	1	Interfaces with bolt to fasten	

4.3.2 CAD Modelling (New Design of Table Fan)

The 16 different parts and total 24 componets of improvement table fan will be assembly according sequences in CATIA V5R20 as shown in Figure 4.1. All draftings for each part can be referred from Appendix C until Appendix P.

Figure 4.1: CAD modeling of new design

4.4 Analysis of the New Design

4.4.1 Theoretical Minimum Part

The three elements which are movement, isolation and material needed to be considering in this analysis. The theoretical minimum part count for the product is obtained when it is answering the necessary for the three criteria elements. If the answer to all criteria is “No”, then the part cannot be considered as theoretically necessary. On the other hand, it is considered as theoretical minimum part count if either one of the elements is "Yes". However, the theoretical minimum part count is considered on the number of essential part of the product and no cost and time considerations. It is important criteria when calculating the design efficiency of this new design of table fan. In Table 4.8 is showed the theoretical minimum part count of the new table fan. In DFMA analysis, there were 10 essential theoretical parts of the new table fan.

Table 4.8: Theoretical minimum part count for new design of table fan

No	Part Name	Movement	Isolation	Material	Theoretical Part	Justification
1	Front fan cover	No	Yes	No	✓	Front fan cover need to isolated in order to assemble blade unit easier.
2	Rear fan cover	No	Yes	No	✓	Rear fan cover need to isolated in order to assemble blade unit easier.
3	Blade unit	Yes	Yes	Yes	✓	This component operates as a rotating part so it is an essential part.
4	Rear plate fastener	No	No	No	X	Unnecessary due it can be combined as one part with other part.

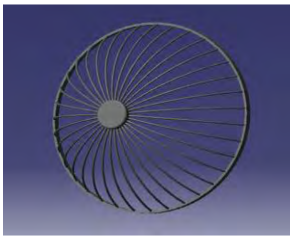
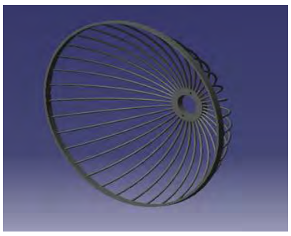
5	Front motor cover	No	Yes	No	✓	Necessary since it need to protect motor from touced the unit blade.
6	Motor housing	No	Yes	No	✓	It is no movement to occur but it need to assemble with other part.
7	Lower part stand casing	No	No	No	X	This part can be eliminate and combined with stand.
8	Fan head coupling	Yes	Yes	No	✓	Since it need to support the head of fan for movement,thus it necessary part.
9	Shaft	Yes	Yes	No	✓	Necessary since to rotated the unit blade.
10	Stand	No	Yes	Yes	✓	The main part to support fan to stand.
11	Switch	Yes	Yes	Yes	✓	Necessary since it need to change the speed of fan.
12	Knob	Yes	Yes	No	✓	This part is rotating part and need for adjust the angle of fan.

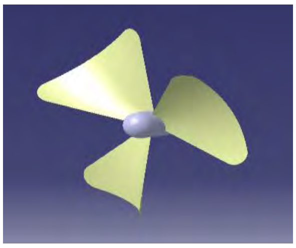
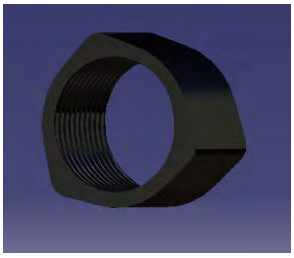
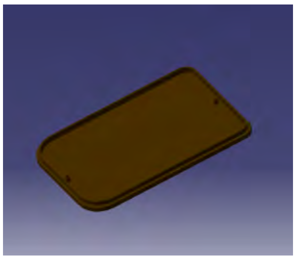
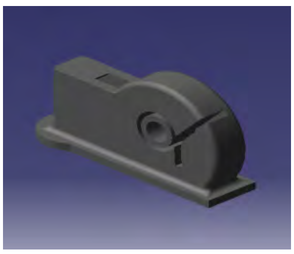
13	Screw	No	No	No	X	The screw can be eliminated by replaced from other type of assembly.
14	Bolts	No	No	No	X	The bolts can be eliminated by replaced from other type of assembly.
15	Nut	No	No	No	X	The nut can be eliminated by replaced from other type of assembly.

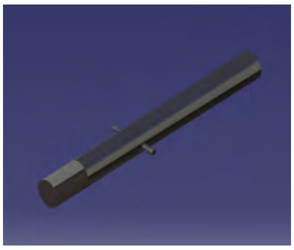
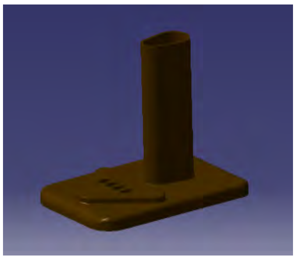
4.4.2 Alpha and Beta Symmetry

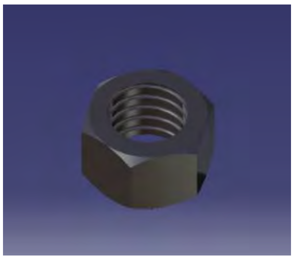
The detail result between the Alpha and Beta symmetric of each part of new table fan design in shown in Table 4.9.

Table 4.9: Alpha and Beta symmetric of new design

NO	PART NAME	FIGURE	Alpha (α)	Beta (β)
1	Front fan cover		0	360
2	Rear fan cover		360	360

3	Blade unit		0	180
4	Rear plate fastener		0	360
5	Front motor cover		360	360
6	Motor housing		360	360
7	Lower part stand casing		360	360
8	Fan head coupling		360	360

9	Shaft		0	360
10	Stand		0	0
11	Switch		360	180
12	Knob		360	0
13	Screw		360	0
14	Bolts		360	0

15	Nut		180	0

4.4.3 Design Efficiency

Table 4.10: Design efficiency for new design of table fan

No.	Item name	Number of items	Total angle of symmetry (α+β), °	Manual handling code	Handling time per item, s	Manual insertion code	Insertion time per item, s	Total operation time, s	Figures for min. parts
1	Front fan cover	1	360	10	1.5	06	5.5	7.0	1
2	Rear fan cover	1	720	30	1.95	06	5.5	7.45	1
3	Blade unit	1	360	00	1.13	00	1.5	2.28	1
4	Rear plate fastener	1	360	10	1.5	00	1.5	3.0	0
5	Front motor cover	1	720	30	1.95	06	5.5	7.45	1
6	Motor housing	1	720	30	1.95	02	2.5	4.45	1
7	Lower part stand casing	1	720	30	1.95	00	1.5	3.45	0
8	Fan head coupling	1	720	30	1.95	07	6.5	8.45	1
9	Shaft	1	360	10	1.5	39	8.0	9.5	1

10	Stand	1	0	00	1.13	00	1.5	2.63	1
11	Switch	1	540	20	1.8	06	5.5	7.3	1
12	Knob	1	360	10	1.5	01	2.5	4.0	1
13	Screw	9	360	60	4.8	38	6.0	97.2	0
14	Bolts	1	360	60	4.8	38	6.0	10.8	0
15	Nut	1	180	40	3.6	30	2.0	5.6	0
							Total	TM	NM
								180.56	10
							Design Efficiency	0.1661	

For new conceptual table fan design, it undergoes same step as analysis on table fan of existing product. Based on the analysis, the design efficiency of the product for new design of table fan is 16.61%. The total operation is 180.56s and it has 10 theoretical minimum parts. The formula of design efficiency can be refer on Eq.(2.5). Following is the calculation of design efficiency for new design of table fan:

$$\textbf{Design Efficiency} = \frac{\mathbf{3 \times NM}}{\mathbf{TM}}$$

$$= \frac{\mathbf{3 \times 10}}{\mathbf{180.56}}$$

$$= \mathbf{0.1661 \text{ or } 16.61\%}$$

4.5 Discussion

4.5.1 Introduction

This chapter discusses about the analysis result of the two differences of existing products by using Manual Boothroyd Dewhurst Design for Manufacturing and Assembly (DFMA) method. The number of parts, total assembly time, theoretical minimum part count and the percentage of design efficiency for both existing product will be compared and briefly discussed in this chapter. The comparison between existing and new conceptual design in term of design efficiency also will be discussed.

4.5.2 Comparison between Two Difference Brands of Products

Based on the result, the table fan (National) design contains total 20 different parts and in total of 29 components. The total operation time takes by table fan (National) is 288.71s and it contain 10 theoretical minimum parts count (TPC). The DFMA analysis evaluates that the design efficiency for table fan (National) is 10.39%. Meanwhile for table fan (Pensonic), it has 18 parts and 23 components including the repeating parts. . The total operation time takes by table fan (Pensonic) is 269.66s and it has same theoretical minimum parts count as National which is 10. The analysis evaluates that the design efficiency for this product is 11.12%.

The design efficiency analysis result as shown in Table 4.5 and Table 4.6 indicated that the design efficiency of table fan for Pensonic is higher than National. It is due to total part number consist on the products and the installation method used during the assembly of the products. In DFMA analysis showed that the table fan for National has 20 different parts while for Pensonic has 18 different parts. The operation time for Pensonic takes less 19.05s compared to National during assembly process. This proved that the total number of part consist in a product effecting the assembly time process as well as the design efficiency of the product.

For theoretical minimum part count analysis, both table fan design contain 10 TPC which is knob, front motor cover, motor housing, front fan cover, rear fan cover, blade unit, fan head coupling, shaft, stand and switch. So the other parts like screws, threaded cap for blade and lower part stand casing can be eliminate or combine as one components in future design.

Based on DFMA analysis result, the design efficiency of table fan for National is 10.39%.and for Pensonic is 11.12%. This percentage of design efficiency is clearly showed that the design for Pensonic is much easier to assemble compared to table fan (National). This stated that table fan (Pensonic) is much superior in term of its operation and design efficiency.

4.5.3 Comparison between Existing Products Design and New Design

The design efficiency between the existing products design and new design is identified by using manual Boothroyd Dewhurst (DFMA) analysis method. Based on Table 4.11, the percentage of design efficiency, quantity of components and total operation time between both existing products design of table fan and new design is shown.

Table 4.11: Comparison between existing products and new design

Item	Existing Design		New Design
	National	Pensonic	
Percentage of Design Efficiency	10.39%.	11.12%.	16.61%.
Parts Quantity	20	18	15
Total Operation Time	288.71s	269.66s	180.56s

In Table 4.11 showed some modification will help the product to save a lot of total operation time during assembly process as well as the design efficiency. The modification by combined blade and threaded cap for blade can be save 3.0s when assembly. Besides that, by eliminates some screws also help to reduce the operations time. This method can be exchanged by using snap or chassis method which is more efficiency but gives the same function.

For the overall result, the new conceptual table fan design have save a lot of total operation time and reduce the number of total components according to DFMA analysis result. Therefore, the new conceptual design shown the improvement in the percentage of the design efficiency which is increases 5.49% compared to Pensonic and 6.22% compared with National. The total operation time also can be cut down around 89.15s to 180.15s in new conceptual design.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As the conclusion, this project is evaluation and comparison the design efficiency of different brands of table fan that available in the market by using DFMA approach. The two difference brands of existing table fan are National and Pensonic. The DFMA approach is implemented clearly in this project.

For table fan (National), it is contain 20 differences part and total 29 components while table fan (Pensonic) contain 18 parts and 23 components in total. In DFMA analysis result showed the total operation time for National is 288.71s while table fan Pensonic is 269.66s. The percentage of design efficiency of table fan (National) is 10.38% and Pensonic is 11.12%.

This is verified that the table fan (Pensonic) design is much easier to assemble compared to brand National. As the result obtained, the table fan (Pensonic) is superior to the table fan (National) in terms of assembly operation and design efficiency. Therefore, the implementation of the modifications is proposed an improvement design based on the existing table fans.

For the new conceptual design of table fan, the total number of components is reduced to 23 components and 15 parts. In DFMA analysis approach, the total operation time reduced to 180.56s. It is obviously show that the operation time can be cut down around 89.15s to 180.15s in the new conceptual design. The percentage of design efficiency for new conceptual design is 16.61%. Thus, it approved that the improvement that have been made shows higher design efficiency compared to existing products.

From overall result, the new conceptual design of table fan has shortened operation time during assembly process and reduces the total number components according to DFMA analysis result. It is also showed the improvement in the percentage of design efficiency in new conceptual design. Meanwhile, it is indirectly shorten the production time and product cost of the table fan. This project is success shown an improvement for a table fan and also achieves the objectives and scope of the project.

5.2 Recommendation

For this project, the improvement table fan in done by using principles of the DFMA approach in modifying the existing table fan and finally came out with a new design of table fan. In facts, there is several method or phases can be performed in order to complete this project. For future improvement and recommendation, I would like to recommend as the future improvement that can be done as follows:

a) DFMA software is recommended to use in Boothroyd Dewhurst (DFMA) method. The DFMA software analysis is more accurate in calculating the design efficiency and contain the cost consideration as well as material used compared to manual DFMA analysis.

b) The design can be improved and approached by using other design tool such as AutoCAD and SolidWorks. So it can be compared the quality of the new design by using Boothroyd Dewhurst (DFMA) method.

c) The Theory Inventive Quandary Solving (TRIZ) and Axiomatic Design (AD) is a suggested method that can be used in future improvement which it provides guidelines for the designer to design a product in order to obtain a better result in term of design efficiency.

With this recommendations, hope that the further improvement or work can be undergoes effectively and lead to better design of the product.

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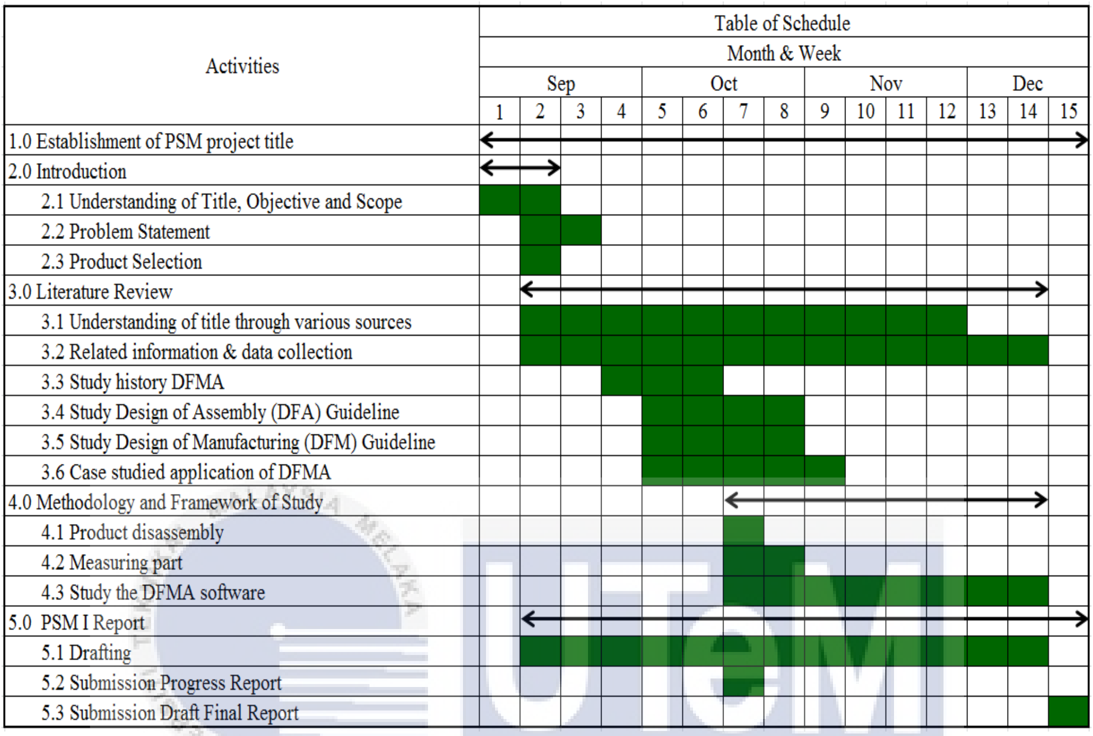
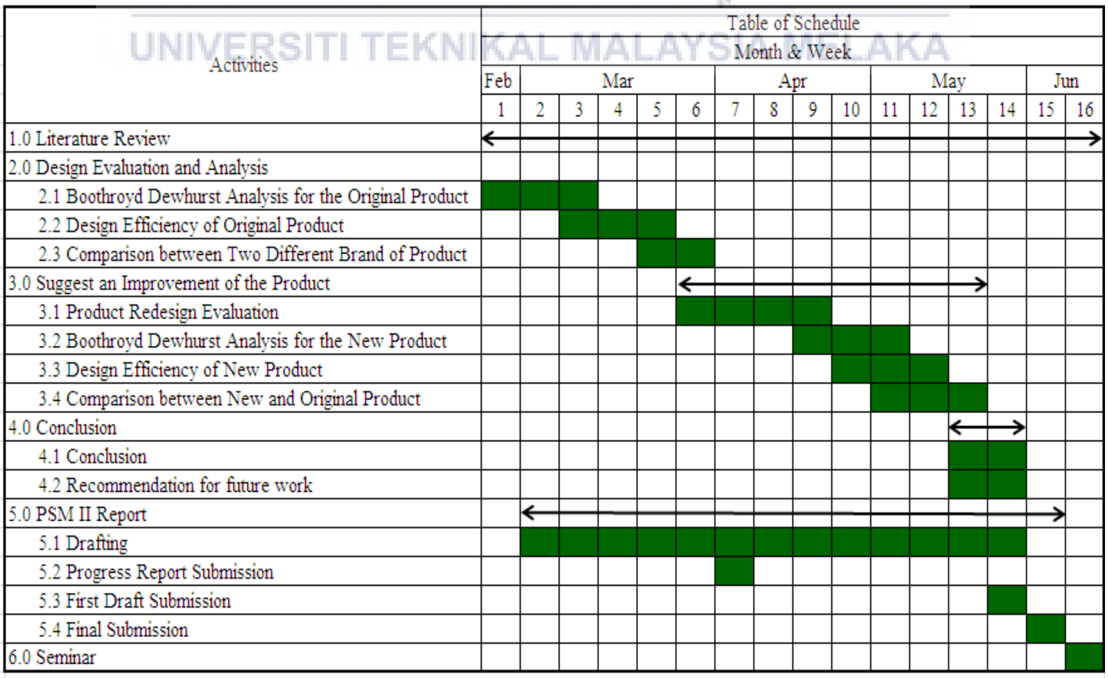
APPENDICES

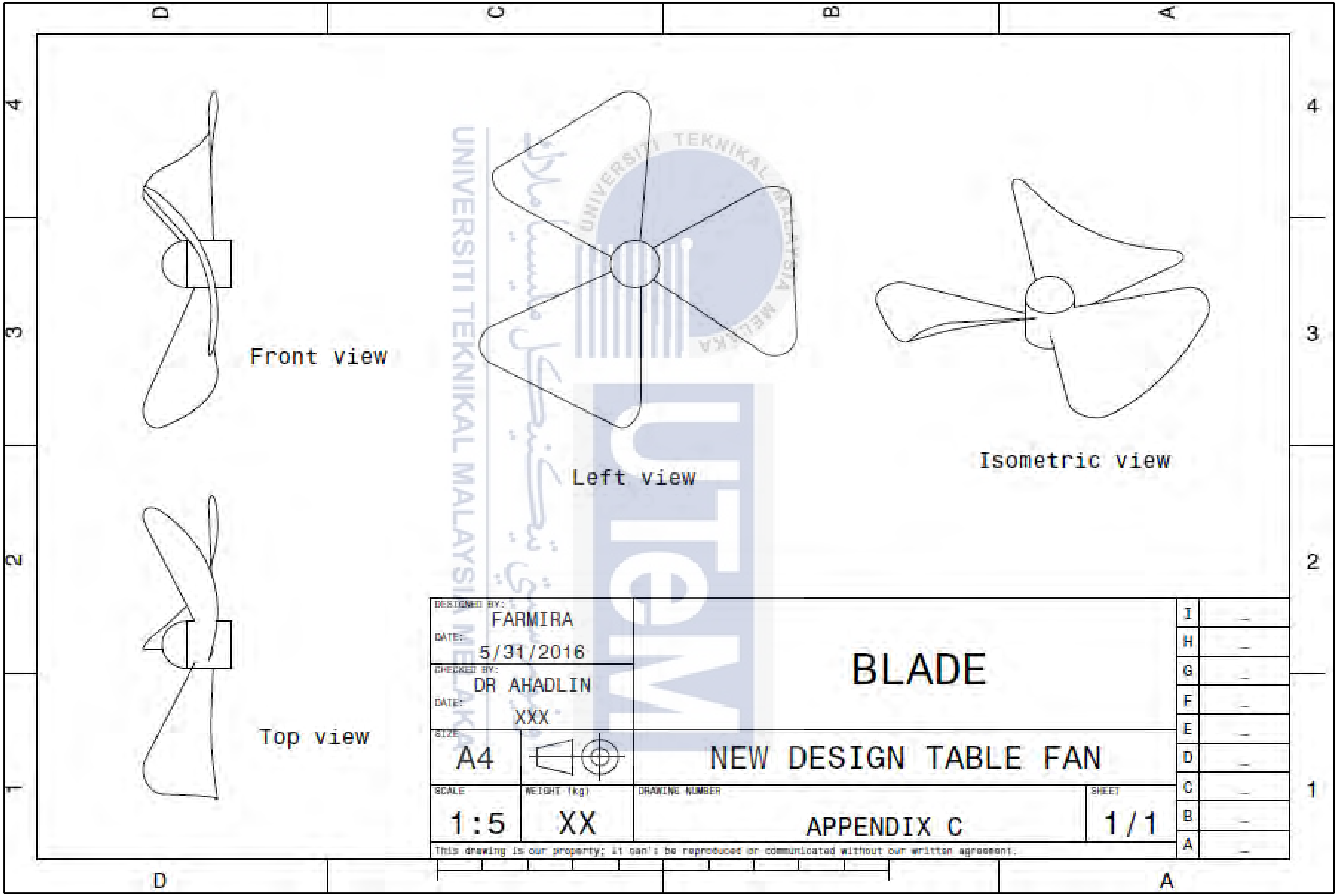


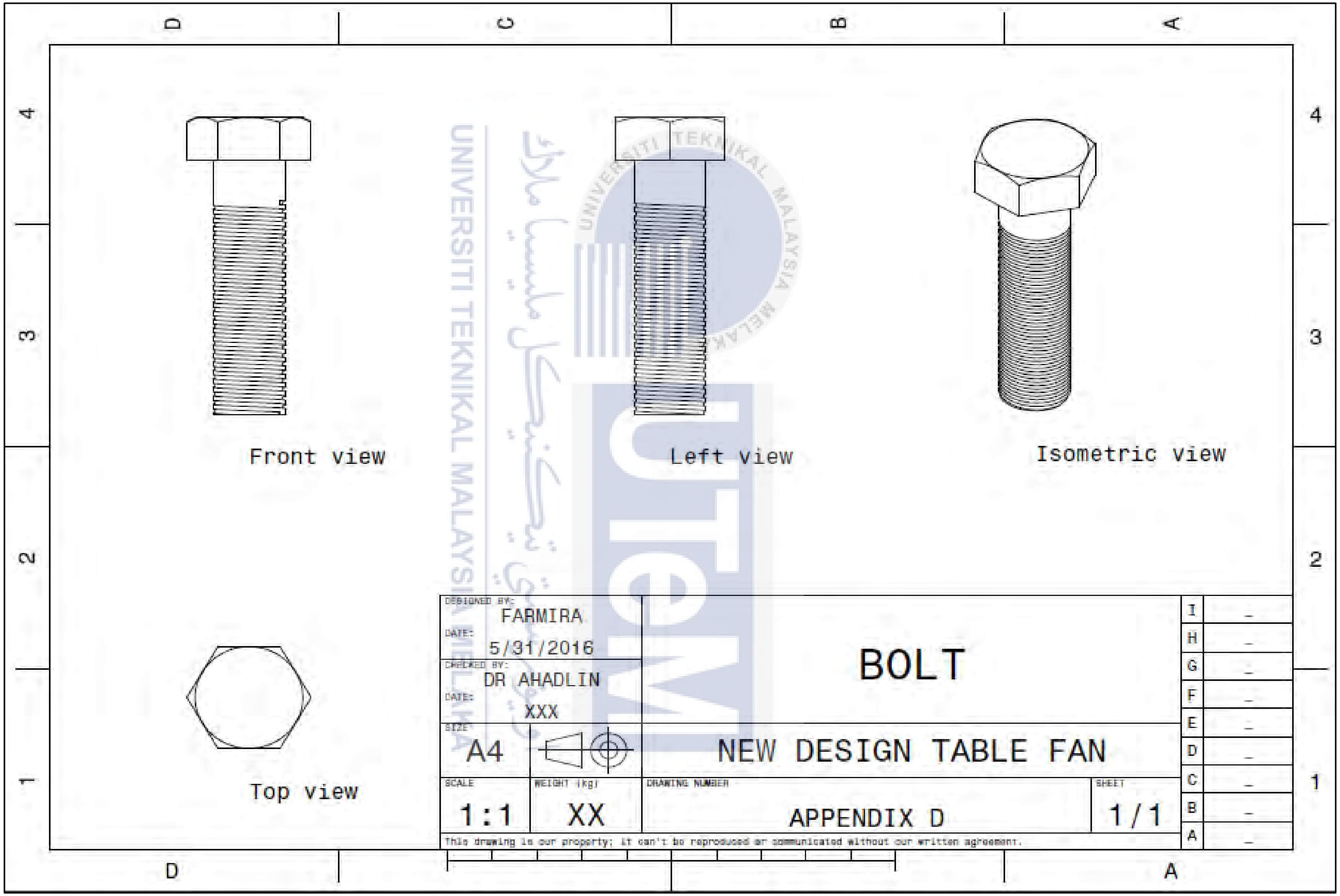
Appendix A: Gantt chart for PSM I



Appendix B: Gantt chart for PSM II

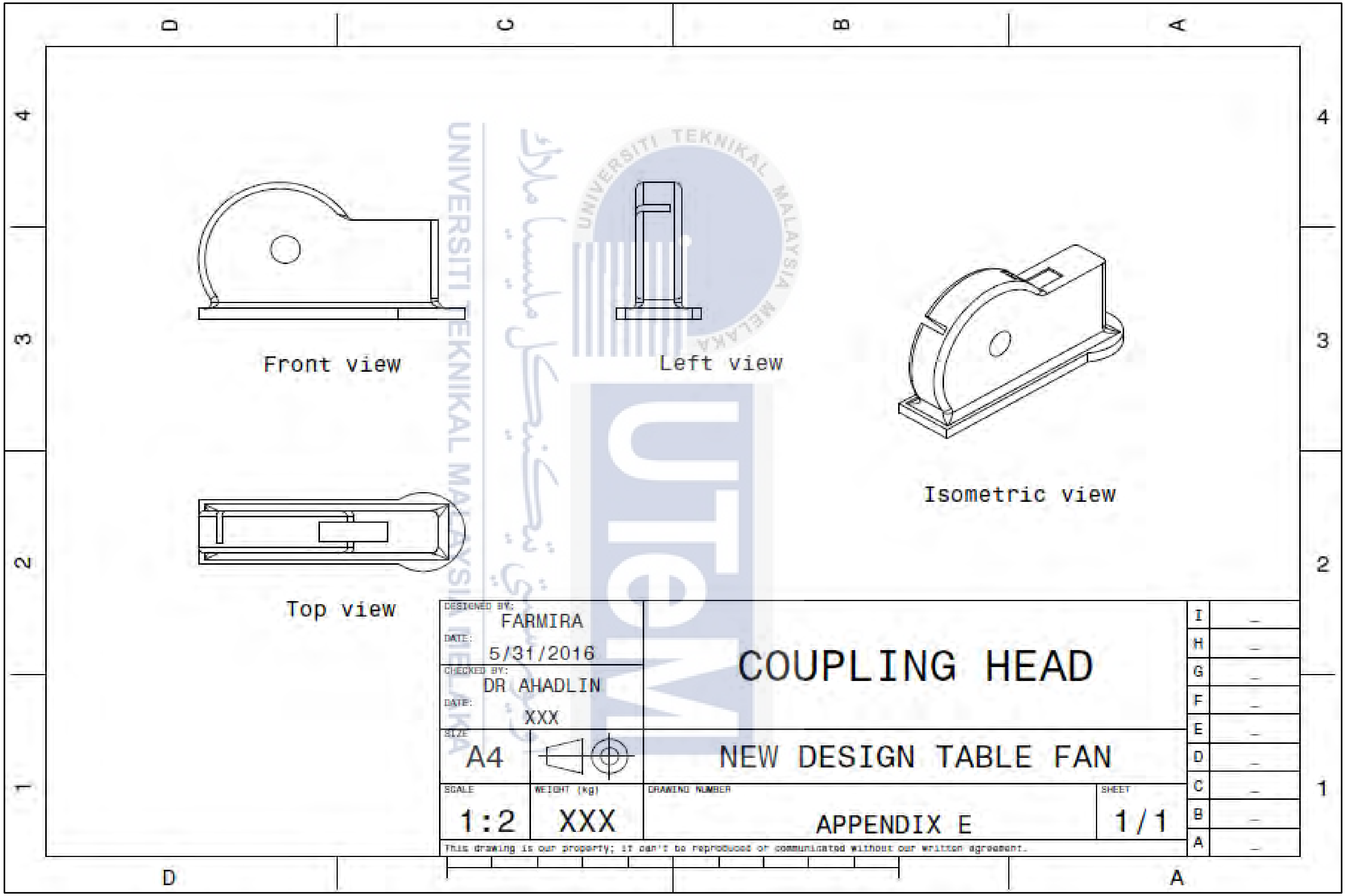
Appendix C: Blade

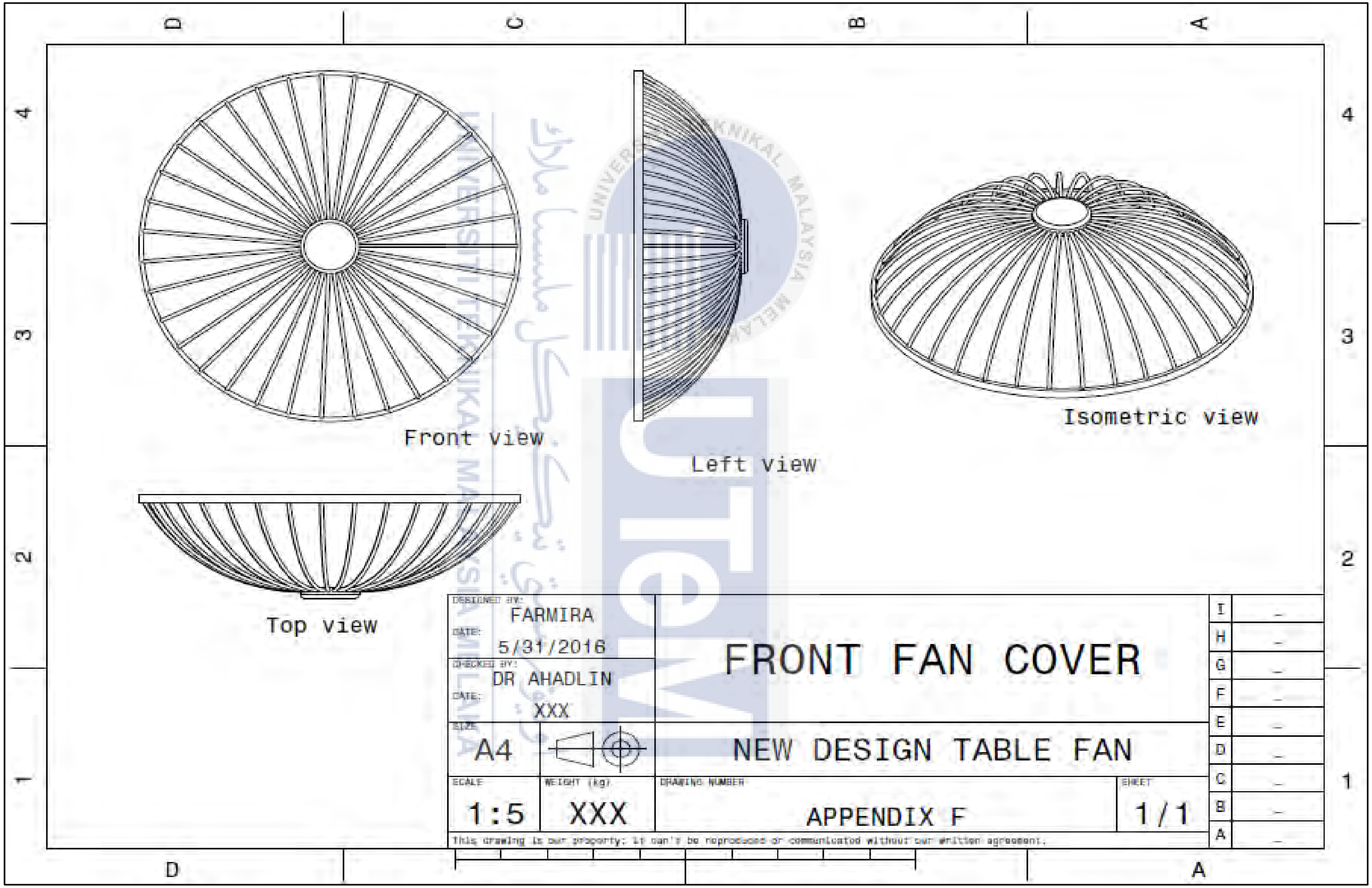




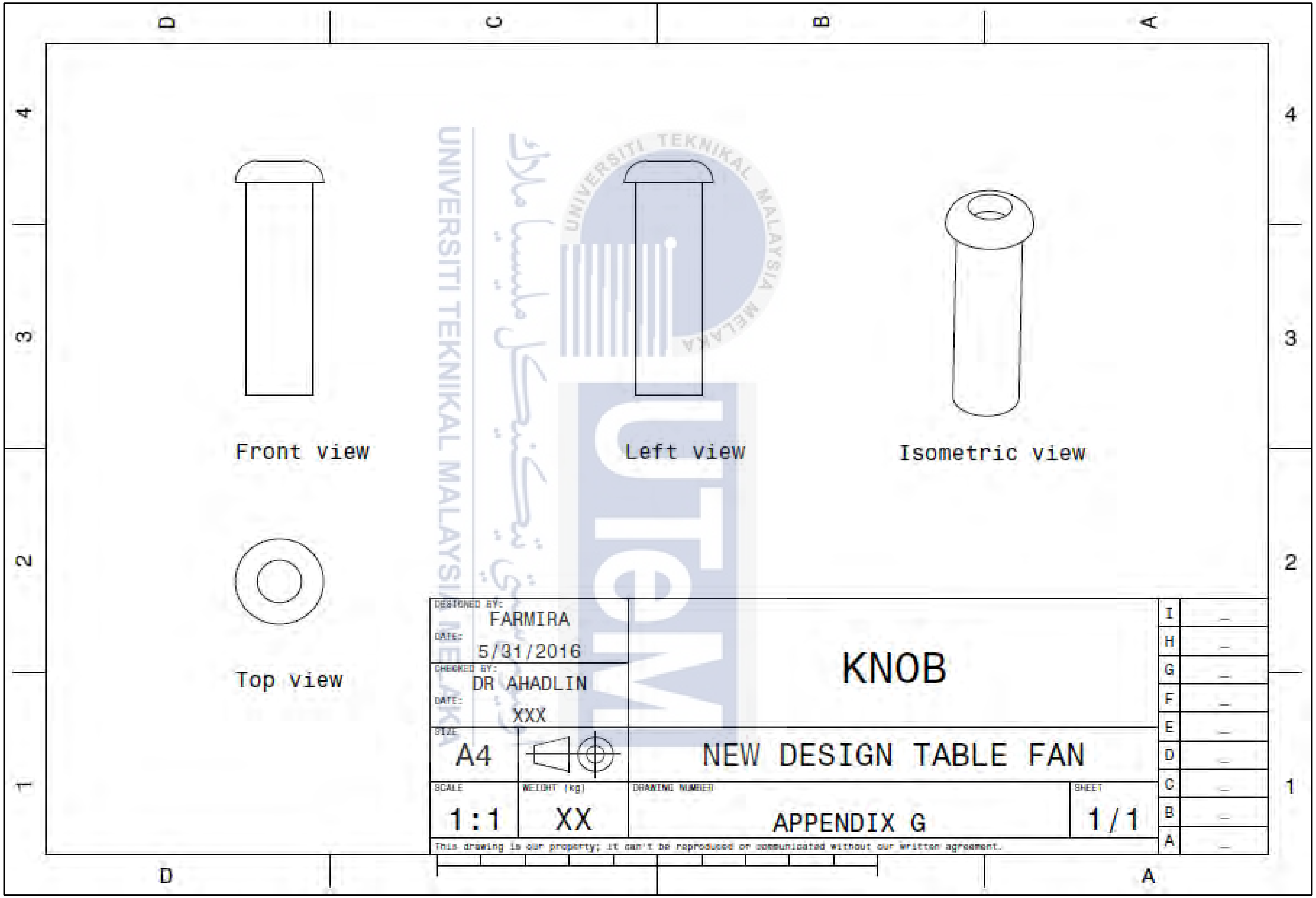
Appendix D: Bolt

Appendix E: Coupling head

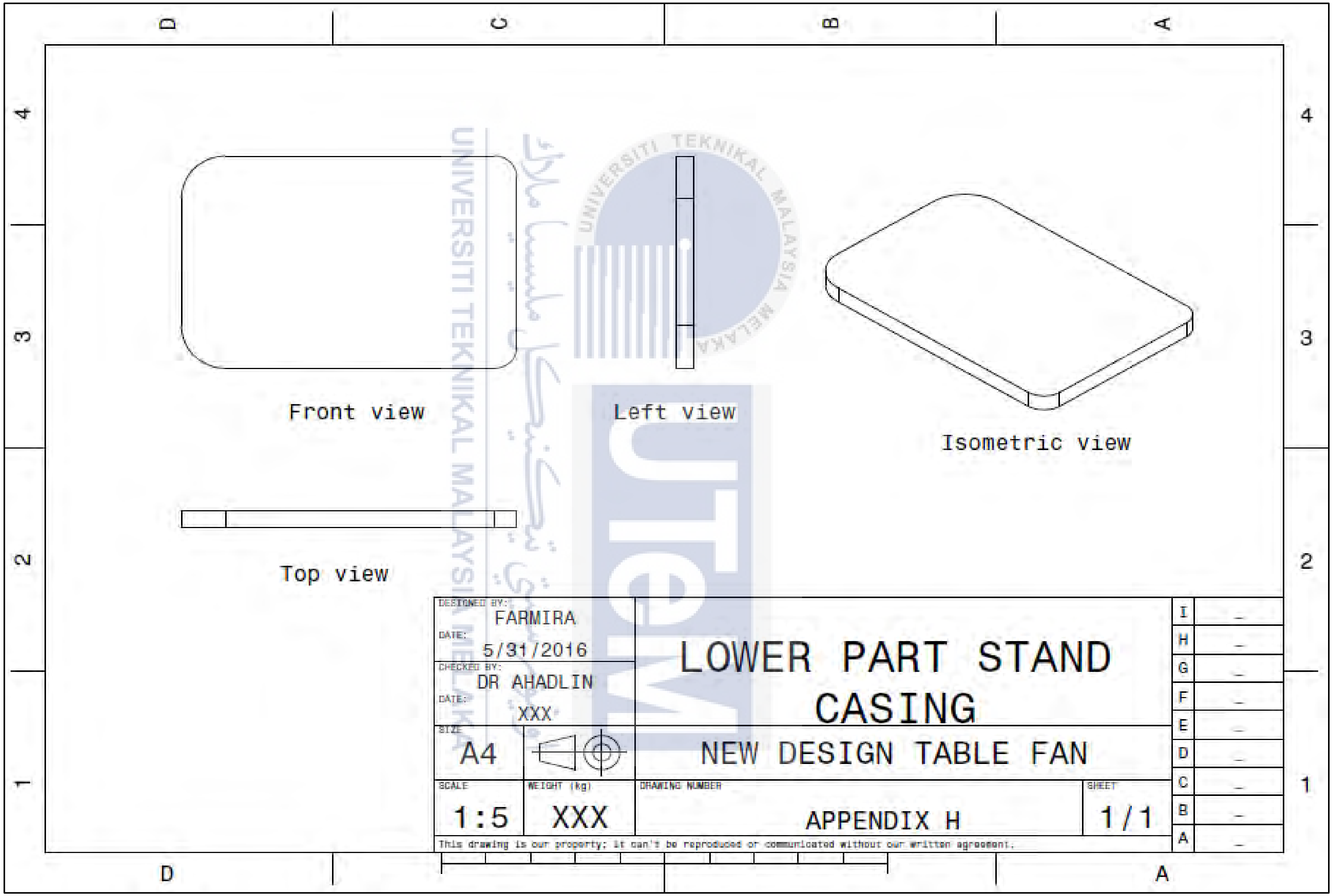




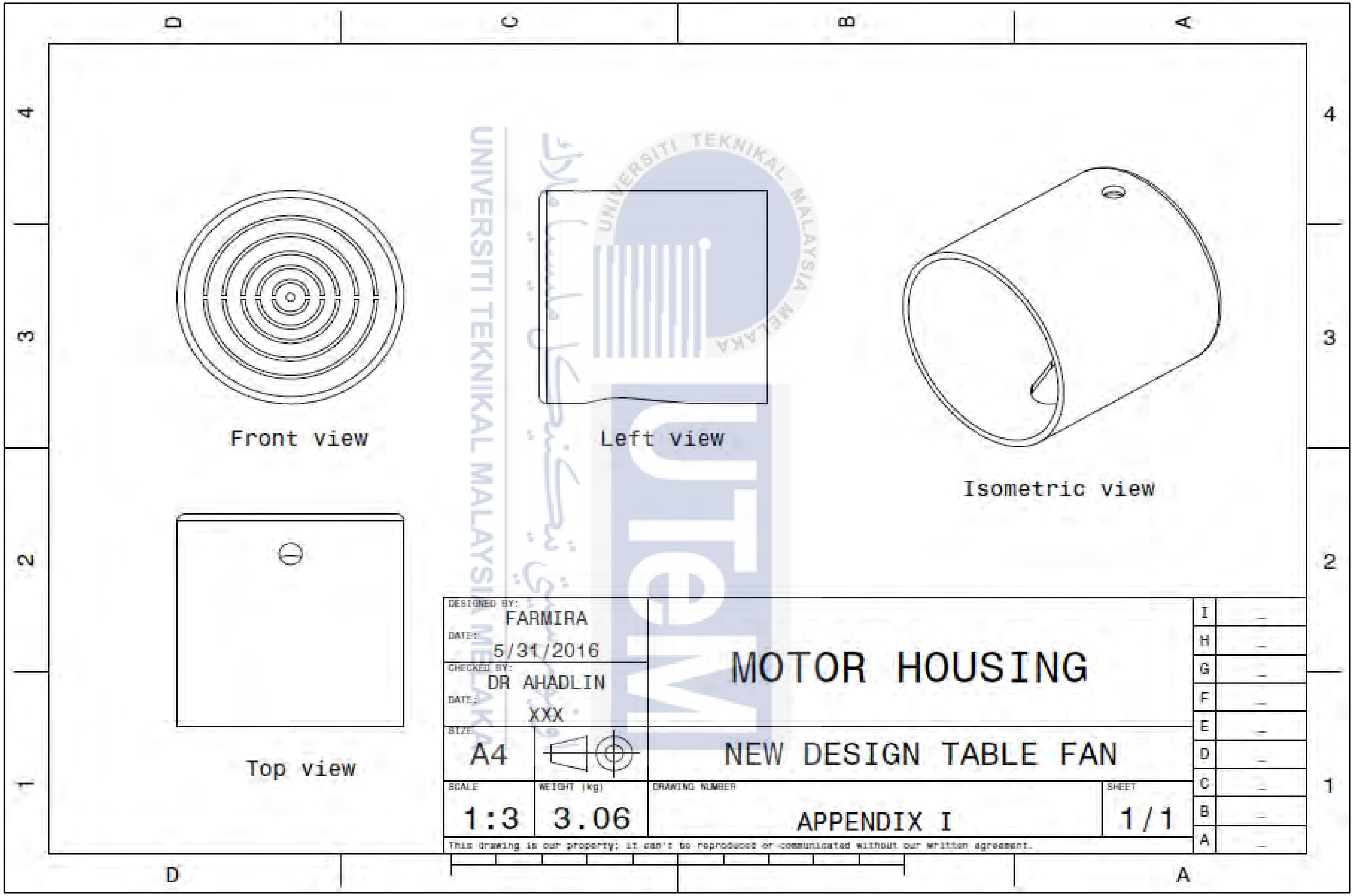
Appendix F: Front fan cover



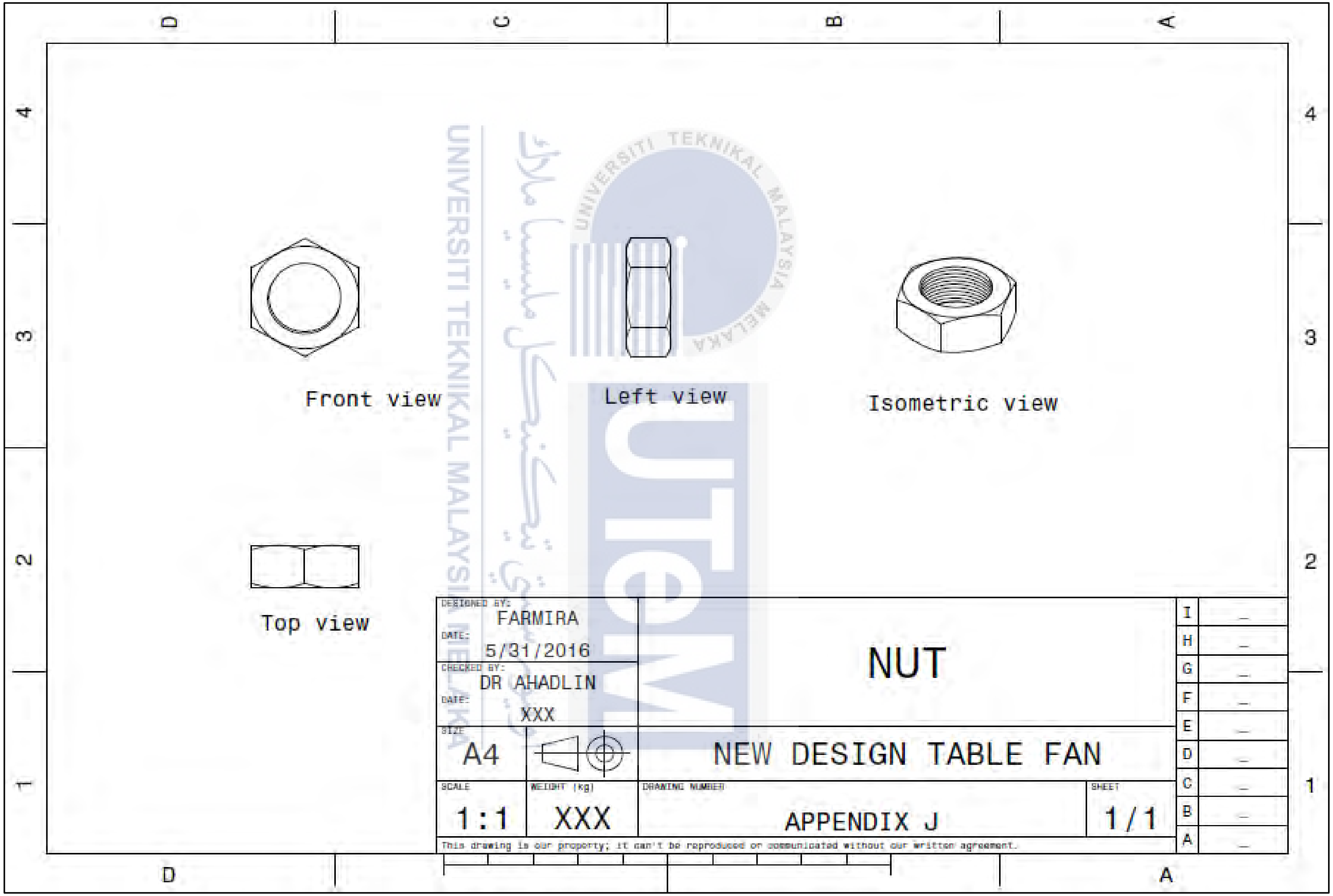
Appendix G: Knob



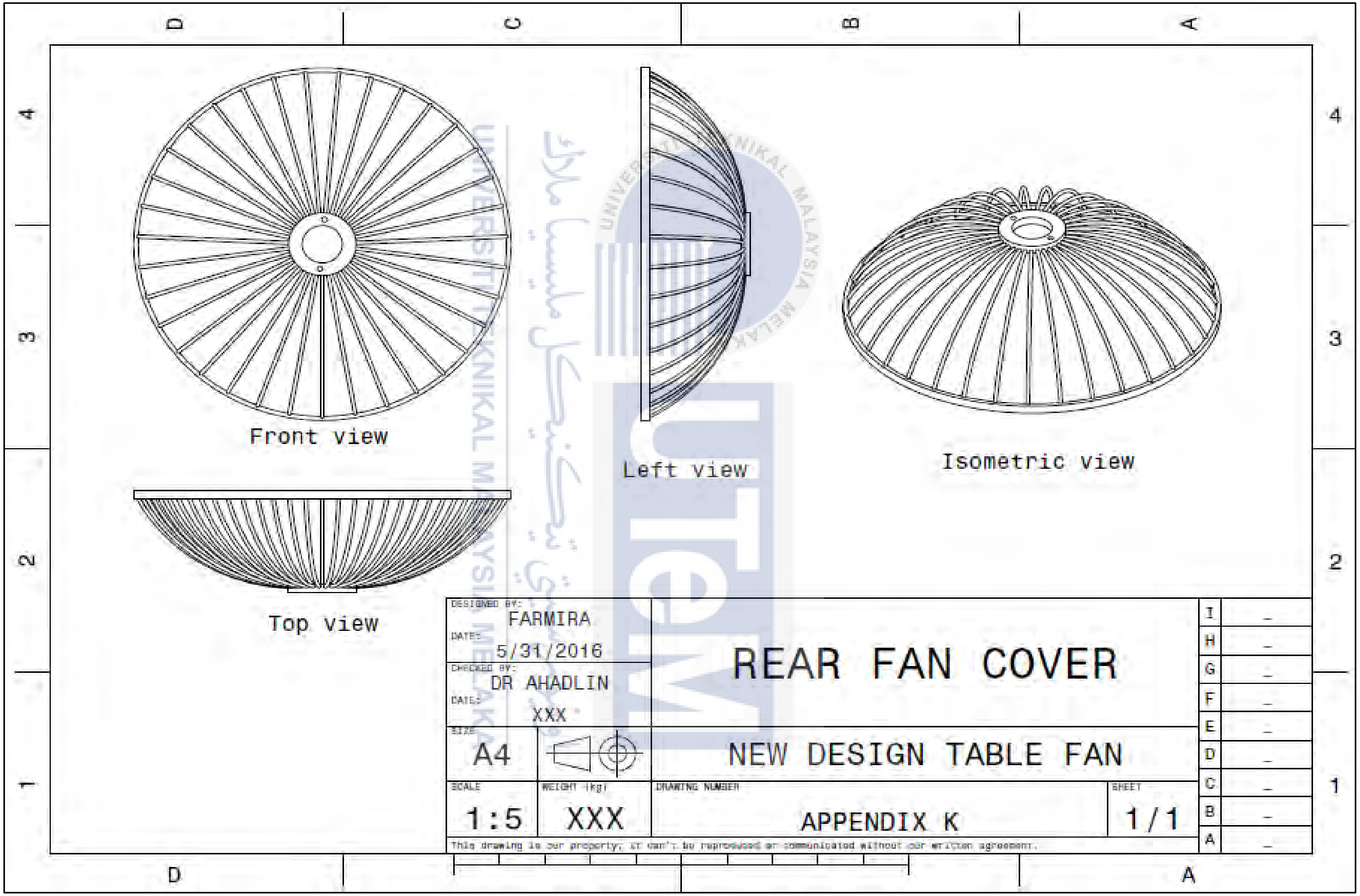
Appendix H: Lower part stand casing



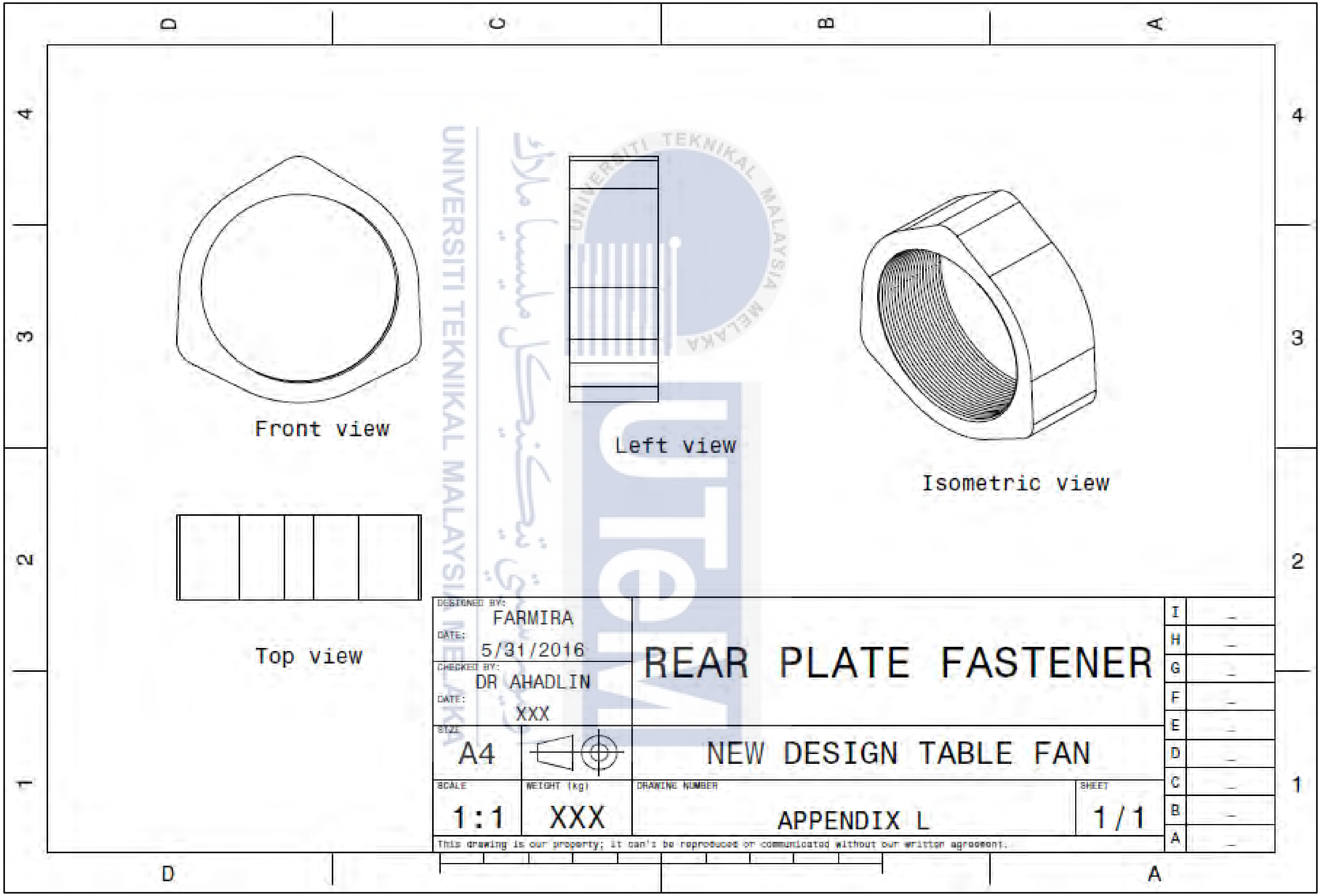
Appendix I: Motor housing



Appendix J: Nut

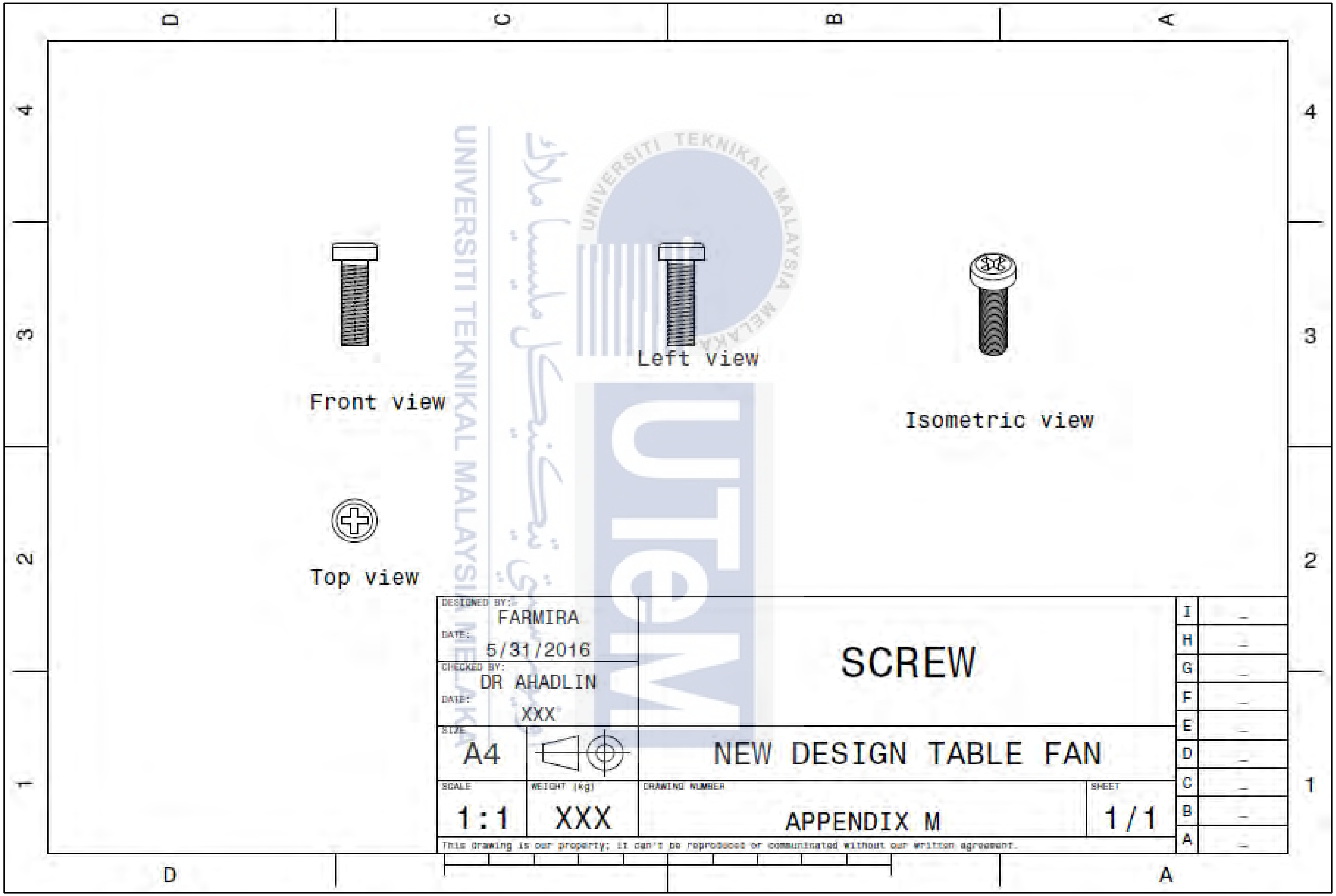


Appendix K: Rear fan cover

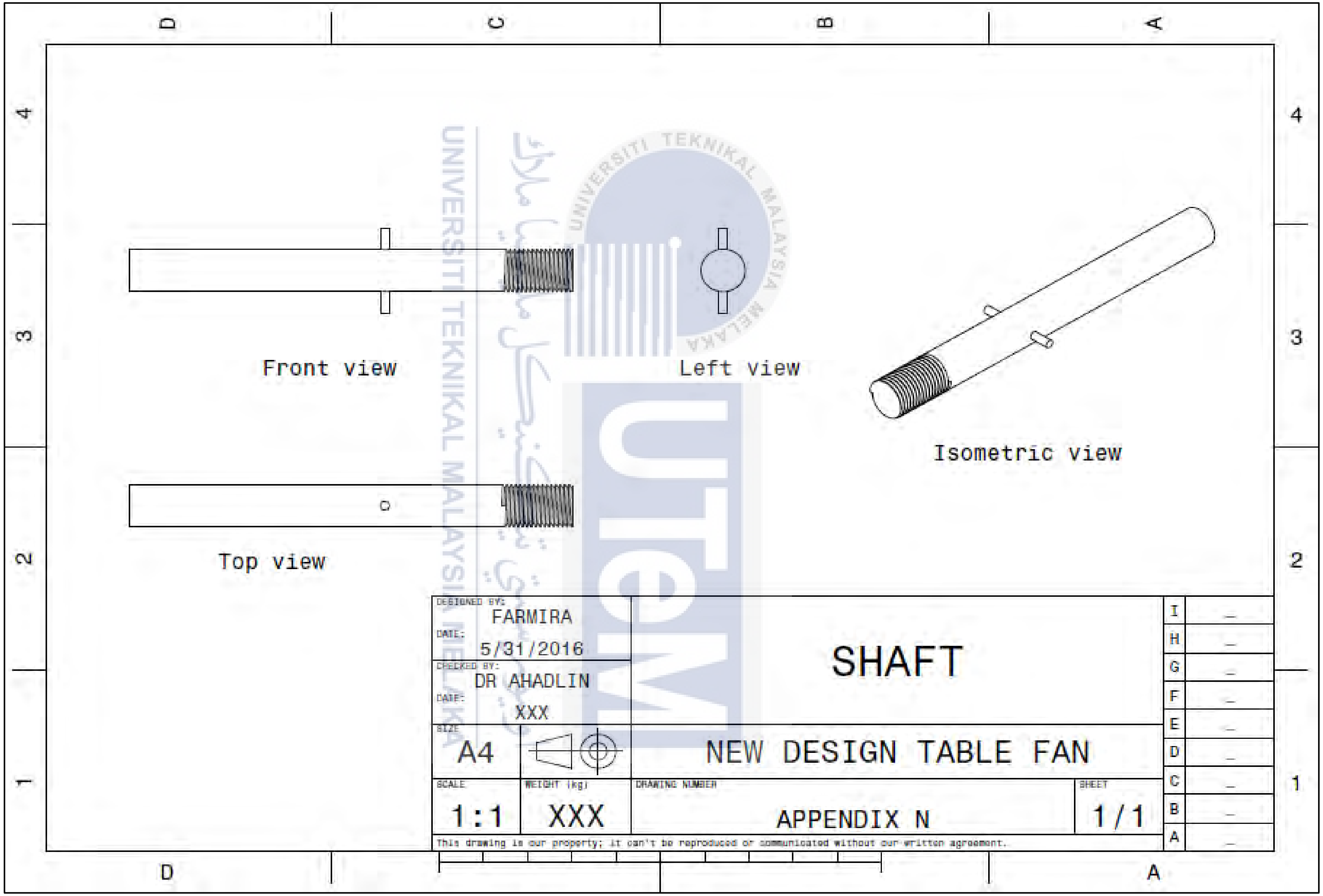


Appendix L: Rear plate fastener

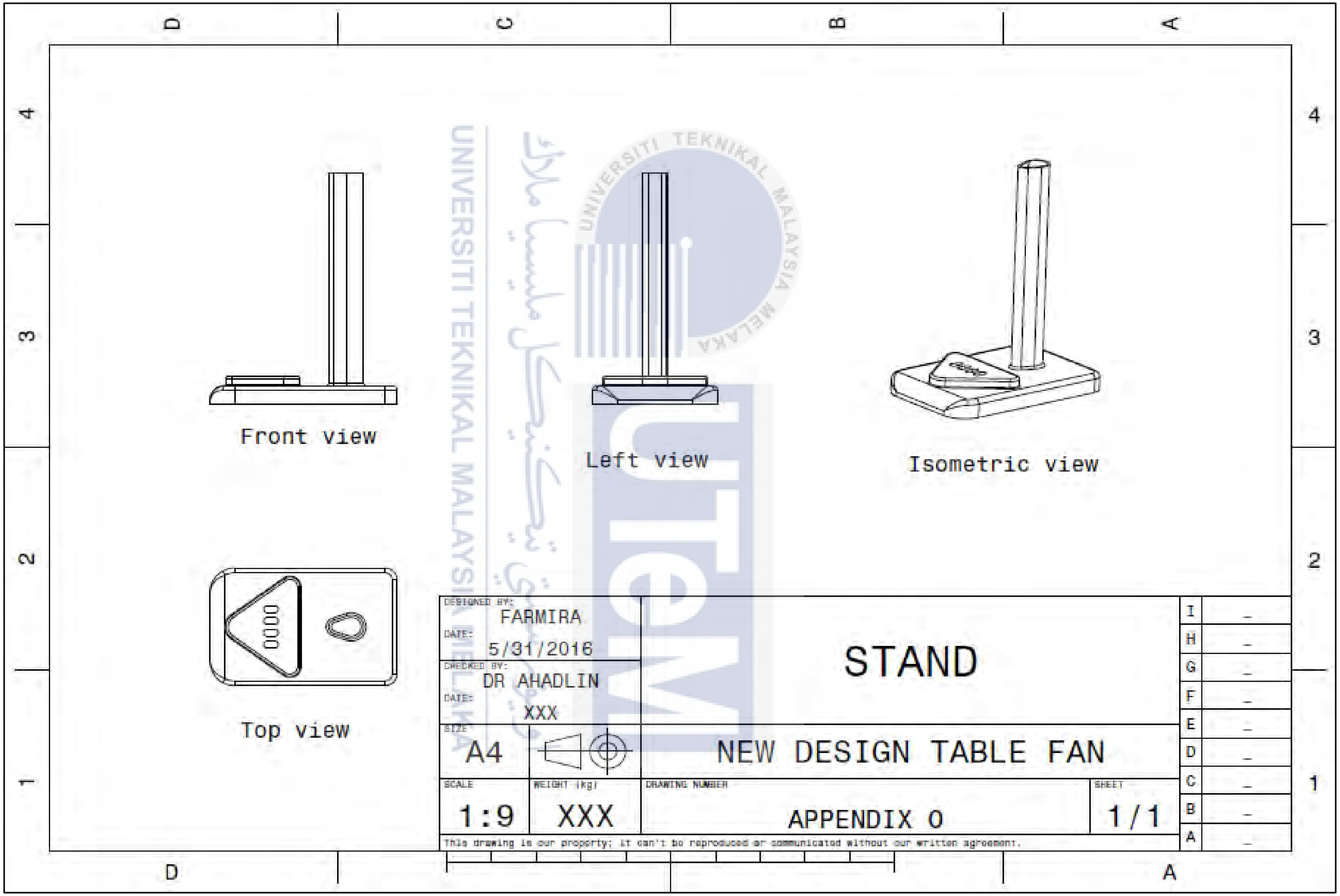
Appendix M: Screw

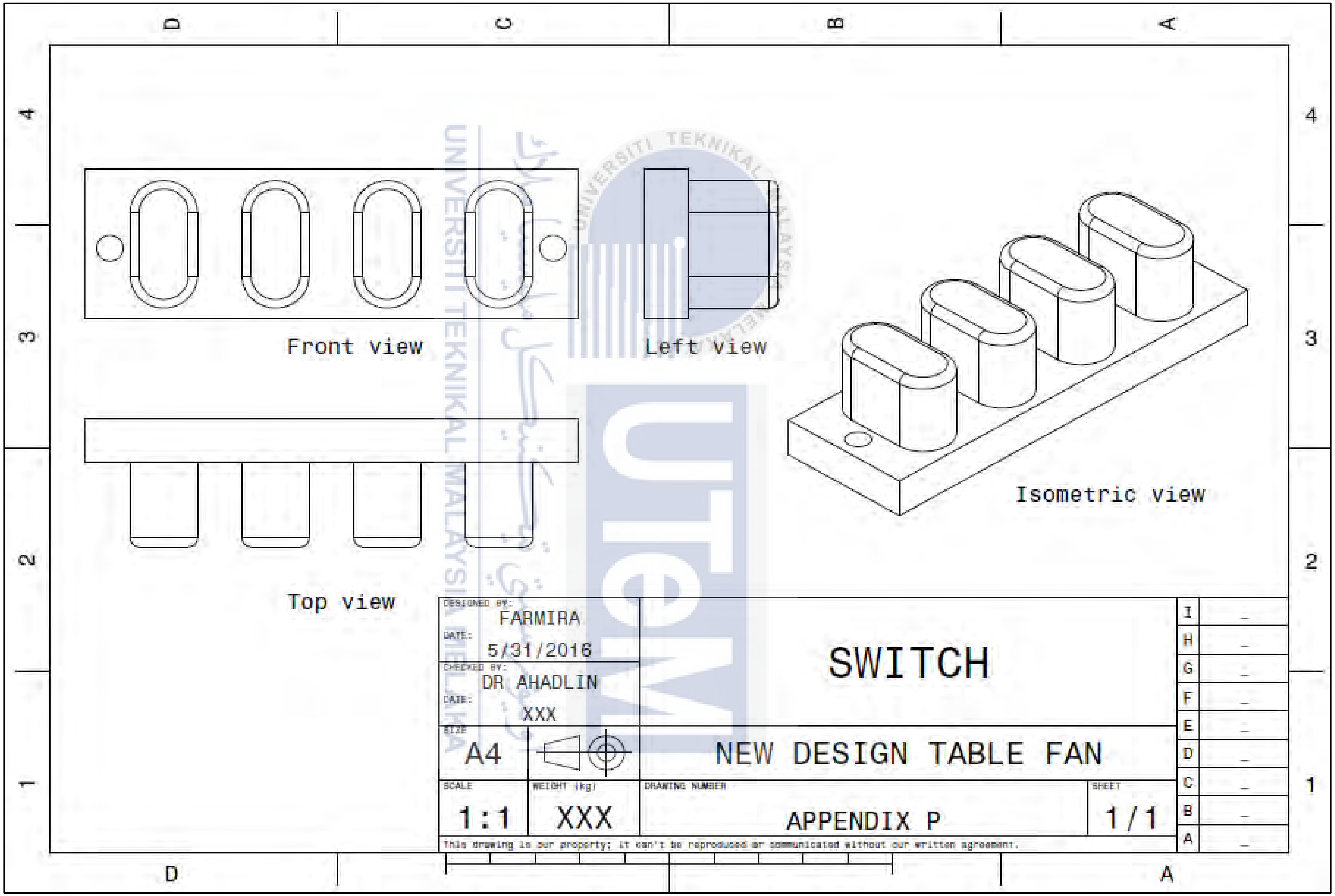


Appendix N: Shaft



Appendix O: Stand





Appendix P:Switch