# DESIGN AND DEVELOPMENT OF THERMODYNAMICS APPARATUS USING DESIGN FOR MANUFACTURE AND ASSEMBLY (DFMA) METHODOLOGY

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To my beloved wife Suriati Aliza bt. Ab. Samad
and my naughty kids; Wan Amirul Arif
I love you all.

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# ABSTRACT

Thermodynamics is an essential subject in Mechanical Engineering curriculum. The thermodynamics principles have been applied in many applications to fulfill human needs. Mechanical engineers use thermodynamics principles in their study to design a wide variety of energy system such as jet engines and rockets, refrigeration system, air conditioning system, chemical process and power plant. This would explain that thermodynamic was one of the critical areas which need to be well understood. However, the majority of students perceive thermodynamics as a difficult subject. By having the suitable experiment apparatus designed to demonstrate thermodynamics process and system have been learned, such an apparatus would enhance the teaching and learning of thermodynamics. Therefore, an apparatus for this purpose is necessary to be developed. The apparatus should be portable and mobilize which demonstration in both lecture and laboratory session is possible. A Boothroyd-Dewhurst Design for Manufacturing and Assembly (DFMA) Methodology had been applied to optimize the design apparatus. The application of Boothroyd-Dewhurst (DFMA) Methodology will simplify the design through minimizing the part component for ease of assembly and manufacture. In addition, this methodology also provides analysis for selection of manufacturing process and material for developed apparatus. Therefore, the overall development cost could be minimized. The aim of this project is to successful develop an apparatus which could demonstrate the 1st Law of Thermodynamics-closed system based on Boothroyd-Dewhurst DFMA Methodology.

# ABSTRAK

Termodinamik merupakan salah satu mata pelajaran asas yang terpenting dalam kurikulum kursus Kejuruteraan Mekanikal. Prinsip-prinsip termodinamik diaplikasikan dalam penciptaan dalam pelbagai peralatan bagi kemudahan kehidupan manusia. Jurutera mekanikal menggunakan prinsip termodinamik untuk mereka bentuk pelbagai jenis peralatan seperti enjin jet dan roket, sistem penyejukan/pendinginan, sistem loji pemprosesan kimia dan sistem loji penjanaan tenaga. Hal ini menjelaskan bahawa bidang termodinamik merupakan satu bidang yang amat kritikal dan amat perlu dikuasai dengan sebaik yang mungkin oleh para pelajar. Akan tetapi sehingga kini, kebanyakan pelajar masih menganggap bidang termodinamik adalah satu bidang yang amat sukar untuk dipelajari. Dengan adanya alat ujikaji yang bersesuaian bagi menerangkan proses termodinamik yang dipelajari, maka sessi pembelajaran akan menjadi lebih menarik dan berupaya memudahkan pemahaman para pelajar. Justeru itu, satu alat ujikaji termodinamik wajar dibangunkan. Alatan ujikaji yang dibangunkan ini adalah bersifat mudah alih yang boleh digunakan untuk demontrasi dalam kuliah dan juga dalam makmal. Bagi mengoptimum reka bentuk alat ujikaji ini, kaedah Reka bentuk untuk Pembuatan dan Pemasangan (DFMA) yang dipelopori oleh Boothroyd-Dewhurst telah digunakan. Kaedah yang diguna pakai ini adalah bertujuan untuk memudah dan meringkaskan reka bentuk alat ujikaji ini dengan meminimumkan jumlah komponen bagi memudahkan kerja pemasangan dan pembuatan. Pemilihan bahan proses pembuatan juga dapat ditentukan melalui kaedah ini. Kesan dari aplikasi kaedah ini adalah kos keseluruhan produk dapat diminimakan. Matlamat akhir projek ini adalah untuk membangunkan satu alat ujikaji makmal yang menggunakan prinsip Hukum Pertama Termodinamik sistem tertutup dengan menggunakan kaedah Reka bentuk untuk Pembuatan dan Pemasangan (DFMA) yang diperkenalkan oleh Boothroyd-Dewhurst.

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| $E_1$ | = | Initial energy |
| $E_2$ | = | Final energy |
| $E_{in}$ | = | Total energy entering the system |
| $E_{out}$ | = | Total energy leaving from system |
| $\Delta E_{system}$ | = | Change in the total energy in the system |
| $E_{final}$ | = | Energy at final state |
| $E_{initial}$ | = | Energy at initial state |
| $\Delta U$ | = | Change in internal energy |
| $\Delta PE$ | = | Change in potential energy |
| $\Delta KE$ | = | Change in kinetic energy |
| m | = | Mass of system, kg |
| $u_2$ | = | Specific internal energy at final state |
| $u_1$ | = | Specific internal energy at initial state |
| $V_2$ | = | Final velocity, m/s |
| $V_1$ | = | Initial velocity, m/s |
| g | = | Gravity acceleration, $m/s^2$ |
| $z_2$ | = | Final height, m |
| $z_1$ | = | Initial height, m |
| Q | = | Heat supplied to system, Joule |
| W | = | Work done by system, Joule |
| $X_1$ | = | Initial position, m |
| $X_2$ | = | Final Position, m |
| P | = | Pressure, Pa |
| V | = | Volume, $m^3$ |
| A | = | Area, $m^2$ |
| F | = | Force, $kg / ms^{-2}$ or Nm |

## LIST OF SYMBOLS (CONTINUED)

| | | |
|---|---|---|
| $v_f$ | = | Specific volume: Saturated liquid, $m^3/kg$ |
| $v_g$ | = | Specific volume: Saturated vapour, $m^3/kg$ |
| $v_{fg}$ | = | Specific volume: Evaporation, $m^3/kg$ |
| $u_f$ | = | Internal energy : Saturated liquid, kJ/kg |
| $u_g$ | = | Internal energy : Saturated vapour, kJ/kg |
| $u_{fg}$ | = | Internal energy : Evaporation, kJ/kg) |
| $v_1$ | = | Specific volume at initial state, $m^3/kg$ |
| $v_2$ | = | Specific volume at final state, $m^3/kg$ |
| x | = | Quality |
| $C_v$ | = | Specific heat of Ideal gas, kJ/kg |
| $T_1$ | = | Temperature at initial state, ºC |
| $T_2$ | = | Temperature at final state., ºC |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction to the Problem

Thermodynamic is an essential subject in Mechanical Engineering curriculum. The thermodynamics principles have been applied in many applications to fulfill human needs. Mechanical engineers use thermodynamics principles in their study to design a wide variety of energy system such as jet engines and rockets, refrigeration system, air conditioning system, chemical process and power plant. These would explain that thermodynamic was one of the critical areas which need to be well understood. However, the majority of students perceive thermodynamics as a difficult subject. Failure to understand the fundamental of thermodynamics will result negative thinking toward the subject. A proposal to integrate between thermodynamics theories and applications during learning process is one of the solutions to avoid negative paradigms among the students. Therefore, an experimental apparatus that applied thermodynamics theory is needed to be developed. This project is carried out to design and develop an experimental apparatus that can demonstrate thermodynamics theory. The aim of developing this experimental apparatus is to integrate between theories learned in lecture room to the real applications. The experimental apparatus had been developed is mainly focused to demonstrate the 1$^{st}$ Law of Thermodynamics-closed system. Design for Manufacturing and Assembly (DFMA) Methodology has been used during design and development stages. The application of DFMA methodology during design and

development is to ensure the developed experimental apparatus is ease to manufacture as well as ease to assemble in cost-efficient and at same time to achieve higher product performance characteristics. As the end result, an experimental apparatus is successful fabricated and ready to use in Thermodynamics laboratory.

## 1.2 Objective of Project

The objective of the project is to design and develop a portable experimental apparatus based on the 1st Law Thermodynamics using Boothroyd-Dewhurst DFMA Methodology.

## 1.3 Scope of Project

The scopes of the project are

1. Understanding the DFMA Methodologies for manual assembly.
2. Application of Boothroyd-Dewhurst DFMA during product assembly analysis and manufacturing process selection.
3. The use of 1st Law Thermodynamics close system in the experimental apparatus.
4. The use of water or gas as working fluid in experimental apparatus.
5. The animation of the proposed design using animation software.

## 1.4 Project Methodology

The project is conducted in two consecutive semesters which are summarized in figure 1.1.

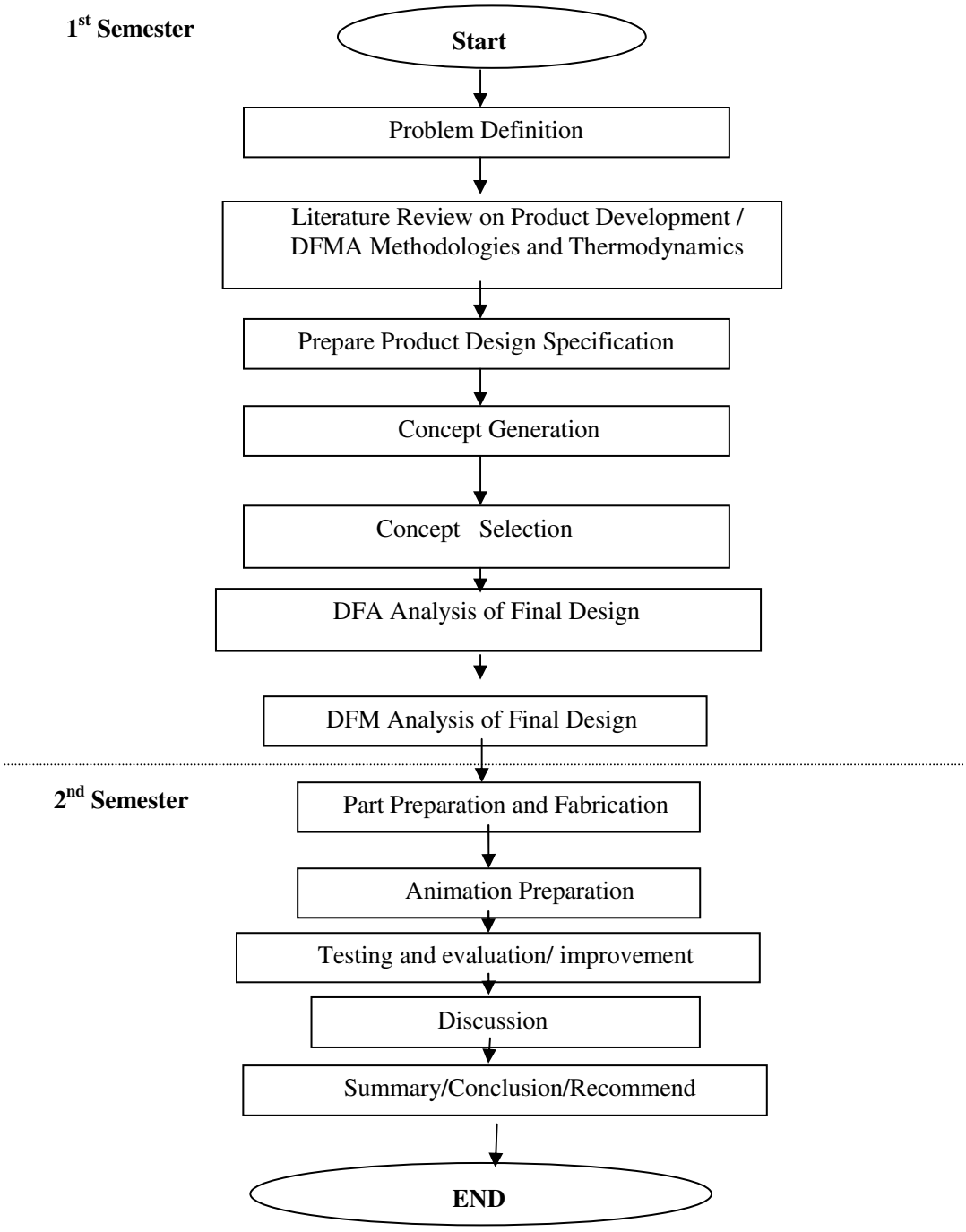


Figure 1.1: Project Flow Chart

The project is accomplished in two semesters. The milestones of project activities are shown in Gantt chart in Appendix A1 for semester 1 and Appendix A2 for semester 2.

In the first semester, the project starts by carrying out a literature review on product development process, continued with Design for Manufacture and Assembly (DFMA) and end up with 1st Law of Thermodynamics theory. The DFMA Methodologies that being discussed are the Boothroyd-Dewhurst DFMA, the Lucas-Hall Evaluation Method, and the Hitachi Assemblability evaluation Method (AEM). The development process continues by preparing Product Design Specification (PDS). The PDS was a product specification that being generated based on user requirements. The next task is to generate several design concepts, then to select the final design concept using concept screening and concept scoring method. Preparation assembly and exploded drawing is also done for DFA analysis. The Boothroyd-Dewhurst DFMA analysis is used to obtain design efficiency also to determine the product material and manufacturing process.

In second semester, the project continues with material preparation and fabrication. The experimental apparatus then will be tested. The evaluation and improvement is carried-out during product testing. Finally, the product performance is discussed and recommendations for future improvement are proposed.

## 1.5 Significant of Findings

The aim of DFMA methodology is to simplify the design. In other word, DFMA target is to minimize components in experimental apparatus. Minimizing the components means fewer components per unit product. Fewer components will lead to reduce the overall production cost. Therefore, the experimental apparatus is expected to be ease of fabrication and assembly. In other perspective, the experimental apparatus will help students to understand the thermodynamics theory. As the final result, student's performance will increase and students may not more perceive thermodynamics as a difficult subject but they will find that thermodynamics is one of the interesting subjects.

## 1.6 Report Structure

The report consists of eight chapters. Chapter 1 is about introduction to the project. An overall picture of the project can understand within this chapter. The objectives and scopes are explained, while the significant of the project is described at the end of chapter.

Chapter 2, deals with a literature review on 1$^{st}$ Law of Thermodynamics, Product Development Process and DFMA Methodology. In 1$^{st}$ Law of Thermodynamics review, the analysis of piston cylinder within close system is clearly overview. Related equations and data are also been provide. Then, a Product Development Process is explain touching steps for systematic of product development is process such as identifying user needs, then generating the concept design is clearly overviewed. The review ends with the concept selection procedure. In DFMA review, three methodologies is described such as Boothroyd-Dewhurst DFMA, Lucas DFA and Hitachi AEM. However, the Boothroyd-Dewhurst DFMA Methodology is explained in details. The chapter concludes with a DFA guidelines during product development process.

Chapter 3 focuses on the development process of the experimental apparatus. This chapter starts with the user requirements, followed by preparation of Product Design Specifications. Concept generation, selection and evaluation are done in this chapter. At the end of the chapter a final design concept is proposed for further development.

Chapter 4 focuses on DFMA analysis of proposed design concept. Starting with preparing the assembly drawing and explode drawing, the DFMA analysis is done using Boothroyd-Dewhurst Methodology. This chapter ends with DFM analysis of main part of the experimental apparatus.

Material preparation and fabrication process of the experiment apparatus is included in Chapter 5. The fabrication processes are showed in sequence using series of photograph. This chapter ends with complete apparatus that ready to the tested.

Chapter 6 deals with development of operating procedure of the apparatus and apparatus testing. The procedure is prepared step-by-step and there are photographs included at every steps performed. To avoid any accident, a safety instruction is given and potential hazards are identified with safety countermeasure. The chapter ends with an analysis of 1$^{st}$ Laws of Thermodynamics using data during testing.

A discussion of overall project is done in Chapter 7. Included in the discussion are product development processes, DFMA application as well as the 1$^{st}$ Laws of Thermodynamics applied in this project. Overall results from the project are also been discussed to evaluate the performance of developed apparatus.

The final chapter gives an overall conclusion about undertaken project. The project achievement is summarized and concluded by referring to the end results gained during completing the project. This chapter ends with recommendation for future work that could be done for further improvement of the apparatus.

## 1.7 Summary

The project to design and development a portable experimental apparatus that demonstrate the First law of Thermodynamics is carried out in two consecutive semesters. The aim of the apparatus is to integrate between thermodynamics theory and application. Boothroyd-Dewhurst DFMA Methodology had been applied in design stage in order to minimize product components as well as to simplify the design for ease of assembly and manufacture. To systematic organize design and development tasks; a project objective, scopes and methodology are prepared to ensure the project started in the right direction until the end.