ANALYSIS OF STIFFNESS AND STRENGTH OF A COMPLEX TOPOLOGY OPTIMIZED THERMOPLASTIC PART DESIGNED FOR 3D PRINTING

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DECLARATION

I declare that this thesis entitled "Analysis of Stiffness And Strength Of A Complex Topology Optimized Thermoplastic Part Designed For 3d Printing" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Muhamad Shahrul Nadzrin bin Ishak

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:	………………………….
Supervisor's Name	:	Dr. Faiz Redza bin Ramli
Date	:	………………………….

DEDICATION

To my beloved mother,
Siti Zaimah binti Mat Salleh,
and
my late father,
Ishak bin Paimin.

ABSTRACT

The analysis of stiffness and strength of a complex topology optimized part designed for 3D printing is a new method to design product beyond a certain level of complexity. The complex part chosen was an engine load bracket which have four load cases applied to it. Topology optimization is a method that used to solve design problems which conventional manufacturing process have constraint during design stage to ensure feasible design. The purpose of this study is to develop an optimized engine load bracket by complying all the requirements assigned. In order to produce a optimized product, many areas need to be studied and analysed such as the material properties, strength, weight, 3d printing fabrication and design improvement. This project carried out all of the necessary background research required to sustain the design requirements. Finite element analysis was used to simulate the conditions of various load applied. This project selects two types of topology optimization method I with design control II without design control to optimized engine load bracket. The result shows two different geometrries after topology optimization was applied. The design result shows different geometry, strength, and weight reduced after topology optimized. The results were compared to original model to analyse the strength after topology optimized was applied. The fabrication of the optimized parts is analysed to have the minimum material usage when printing. 3D printing used support for parts with overhanging geometry, the design improvement after topology optimized is to avoid overhanging geometry of the product. The findings suggest that improvement of the bracket will leads to lower material usage of material and time consumption to fabricate the parts with 3D printing technologies. The parameter findings also related to final design of engine load bracket and fabrication with 3D printing. The final design of engine load bracket with using topology optimization method has potential for future developments and manufacturing. During the development and fabrication of the engine load bracket, some areas for improvement were recognized and future recommendations were suggested.

ABSTRAK

Analisis kekukuhan dan kekuatan bagi pengoptimuman topologi kompleks yang direkabentuk untuk percetakan 3D adalah kaedah baru bagi menghasilkan produk di tahap kerumitan yang lebih kompleks. Produk kompleks yang dipilih adalah enjin beban pendakap yang mempunyai empat kes bebanan di dikenakan pada produk tersebut. Pengoptimum topologi adalah satu kaedah yang digunakan untuk menyelesaikan masalah reka bentuk di mana proses pembuatan konvensional mempunyai kekangan pada peringkat reka bentuk dan penghasilan. Tujuan kajian ini adalah untuk menghasilkan produk yang optimum dengan mematuhi semua penanda aras yang diberikan. Untuk menghasilkan produk yang paling optimum, banyak perkara yang perlu dikaji dan analisis seperti sifat bahan, kekuatan, berat, cara percetakan 3D dan juga penambahbaikan reka bentuk. Projek ini dijalankan untuk semua kajian latar belakang yang diperlukan untuk mengekalkan keperluan reka bentuk. Analisis kekuatan reka bentuk digunakan untuk membuat simulasi keadaan beban yang dikenakan. Projek ini memilih dua jenis kaedah pengoptimum topologi I dengan kawalan reka bentuk II tanpa kawalan reka bentuk untuk produk yang dioptimumkan. Hasil menunjukkan dua geometri berbeza selepas pengoptimum iaitu selepas konsep topologi digunapakai. Hasil reka bentuk menunjukkan geometri, kekuatan dan berat yang dikurangkan adalah berbeza bagi kedua-dua kaedah tersebut. Hasil pengoptimum dibandingkan dengan model asal untuk menganalisis kekuatan setelah pengoptimum dilakukan. Percetakan 3D memerlukan sokongan semasa penghasilan produk. Penambahbaikan reka bentuk selepas topologi yang dioptimumkan adalah untuk mengelakkan geometri yang menggangu produk semasa penghasilan. Penemuan menunjukkan bahawa penggunaan sokongan akan membawa kepada penggunaan bahan yang berlebihan. Reka bentuk terakhir produk dengan menggunakan kaedah pengoptimum topologi mempunya potensi untuk perkembangan masa depan dan pembuatan. Semasa penghasilan dan fabrikasi produk, terdapat ruang untuk penambahbaikan dan saranan untuk dicadangkan pada masa hadapan.

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LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
RP	-	Rapid Prototyping
CAD	-	Computer Aided Design
3D	-	Three Dimension
FDM	-	Fused Deposition Modelling
SLM	-	Selective Laser Sintering
BJ	-	Binder Jetting
SLA	-	Stereolithography
DLP	-	Digital Light Processing
GE	-	General Electric
ELB	-	Engine Load Bracket
TI	-	Titanium
SIMP	-	Solid Isotropic Material with Penalization
ESO	-	Evolutionary Structural Optimization
FEA	-	Finite Element Analysis
BESO	-	Bi -directional Evolutionary Structural Optimization
AESO	-	Additive Evolutionary Structural
NC	-	Numerical Control
STL	-	Standard Tessellation Language
FOS	-	Safety of Factor
STP	-	Standard Exchange for The Product

LIST OF SYMBOLS

In	-	inch
D, d	-	Diameter
F	-	Force
N	-	Newton
%	-	Percent
m	-	Mass
Kg	-	Kilograms
g	-	Grams
mm	-	millimetres
l	-	Length
Gpa	-	Gigapascal
Mpa	-	Megapascal

CHAPTER 1

INTRODUCTION

1.1 Background of Study

We are now currently moving forward in advanced technology for manufacturing process which is called addictive manufacturing (AM). 3D printing or additive manufacturing (AM) which also called as rapid prototyping (RP) is a process to make three dimensional objects from a digital file. 3D printing is used to make a product prototype for product development before mass produce the final product.

3D printing widely been used to make product prototype due to the efficient of the additive manufacturing process rather than conventional process such as casting, injection moulding or machining which requires longer time and higher cost to make product prototypes. However, as speed, material properties, and affordability improve, we observe a trend towards production of end products using additive manufacturing. (Wohler T, 2010).

3D printing requires to design and converted it into 3D Computer aided design (CAD) software and the data is then converted into 3D printing technologies. 3D printing machine will slice the data into thousands of cross sections. These cross-section perimeters are traced either by a laser, electron beam, extrusion nozzle or jetting nozzle and the area contained by the perimeters filled with a hatching pattern (D. Brackett, 2011). Additive manufacturing is a process by layering, each layer is based from virtual cross -section from the CAD data. Layer by layer are automatically are build it up to make the final product. Generally, there are several types of 3D printer technologies that have been used widely such as fused deposition modelling (FDM), selective laser sintering (SLM), binder jetting (BJ), selective laser melting (SLM), stereolithography (SLA), digital light processing (DLP) and so on.

Topology optimization is a method that used to solve design problems which conventional manufacturing process such as casting and have significant constraint during design stage to ensure feasible design. The former manufacturing process used optimal topology to ease manufacturing but not all constraints can be included easily in the optimization process.

The purpose of topology optimization to have to minimum material usage within specified region. This is achieved by minimizing (or maximizing) a property of the structure, subject to constraints and boundary conditions. The design domain is discretized into finite elements, and one of a number of optimization techniques are used to determine which elements should contain material and which should be voids (Ian Ferguson, 2015).

1.2 Problem Statement

In this project, optimizing the stiffness and strength an existing aircraft engine bracket from "GE jet engine bracket challenge" as shown in Figure 1.1. This bracket contains 5 interfaces and have 4 loads applied to it which is 3 static loads and 1 torsional load as shown on Figure 1.2. Aircraft engine bracket play critical role by support the weight of the engine and stay on the engine at all times even during flight. However, this bracket was design by conventional manufacturing technologies and not fully optimized on their stiffness, strength and weight.

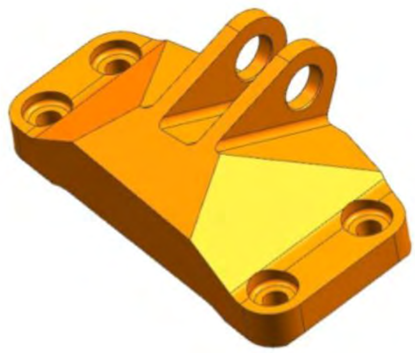

Figure 1.1: Aircraft Engine Bracket

1.3 Objective

Objectives of the project are as follows:

1. To improve the design and structure of the aircraft engine bracket by using Solid Thinking Inspire software.
2. To reduce the weight of aircraft engine bracket by using topology optimization method.
3. To obtain the prototype of aircraft engine bracket after topology optimization by using 3D printer.

1.4 Scope

Scope of the project are as follows:

1. Solid Thinking Inspire will be used to create topology optimization on aircraft engine bracket.
2. Analysis of the new aircraft engine bracket stiffness and strength will be used Solid Thinking Inspire
3. The weight reduces of aircraft engine bracket at least by 40% of original mass
4. The optimization for the whole project is by using Fused Deposition Modelling (FDM) 3D printing.
5. The minimum material usage when printing the protype of aircraft engine bracket.

CHAPTER 2

LITERATURE STUDY

2.1 Rapid Prototyping

2.1.1 Introduction of Rapid Prototyping

3D printing or also known as rapid prototyping is future of the manufacturing process. Rapid prototyping (RP) is a technology that have been developed in the 1980's in the United States. During the 1990's RP was mainly used to create prototypes, today its applications have gone beyond simple visualization (Rodrigo 2012). Rapid prototyping is usually used for produced model or a prototype parts due to it can produce or print a complex shape part. Today, rapid prototyping can be used for a lot of application rather than produce a prototype.

Reasons 3D printing will become the future of manufacturing technology is due to the ability of RP to produce solid object with high-complexity functional products, rapid prototyping can create almost any shape or geometric features. Manufacturing industries have predicted that 3D printing is going to be industrial revolution of manufacturing process.

Rapid prototyping (RP) machine has emerged as a key enabling technology, with its ability to shorten product design and development time. RP techniques can also be used to make tooling and even production of quality parts. For run small production runs and complicated objects, rapid prototyping is the best manufacturing process available. Today's additive technologies offer a lot of advantages if compared to traditional manufacturing process which is subtractive fabrication methods such as milling, lathe or turning.

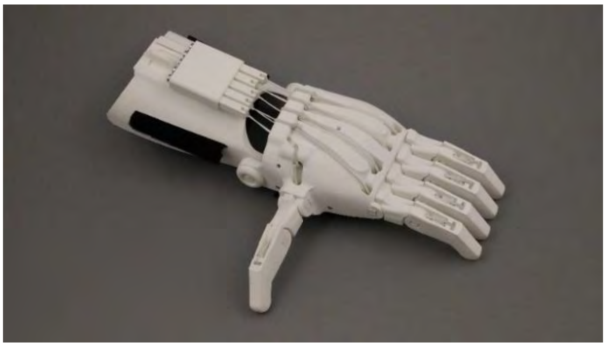

Figure 2.1: Example of Product Print By 3D Printing (www.enablingthefuture.org)

2.1.2 Principle of 3D Printing

Rapid prototyping is an additive manufacturing process that create 3D object from Computer Aided Design data. Computer aided design (CAD) file need to be converted to a stereolithography (STL) file. In this process, the drawing made in the CAD software is approximated by triangles and sliced containing the information of each layer that is going to be printed (Wong and Hernandez 2012).

The information from the STL file are transfer to 3D printing machine and the digital data creates 3D model by adding material from layer by layer. The layers of liquid, powder or sheet material builds up and the model are joined together or fused automatically to create the final shape of the product. The time for completing the final product are depends on the size and complexity of the object. 3D printing allowed to modify the parameter of the printing object You can customize various aspects of the design such as the layer thickness, temperature, and outer finish, etc(Soliman, Feibus, and Baum 2015).

Some additive manufacturing techniques can use multiple materials to construct parts. They can also use multiple colour combinations simultaneously. In case there are projecting parts in the model, supports are used like scaffolding until the overhanging part sufficiently hardens. These supports can be dissolved in water when the model is printed.

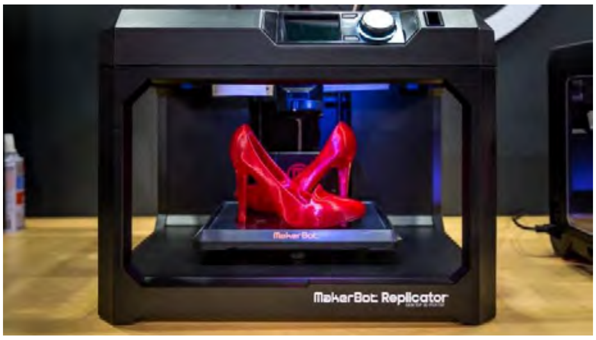

Figure 2.2: Example of 3D Printing Machine (www.tested.com)

2.1.3 Type of Rapid Prototyping

Rapid prototyping can be divided into 3 main section which is Liquid based, Solid based and Powder based. The difference between this 3 is the method of the process. Each method has their unique and advantages, using the correct method for the project of 3D printing could save such as cost, time, and materials. Figure 2.3 below shows the list of additive manufacturing separated by their based and type.

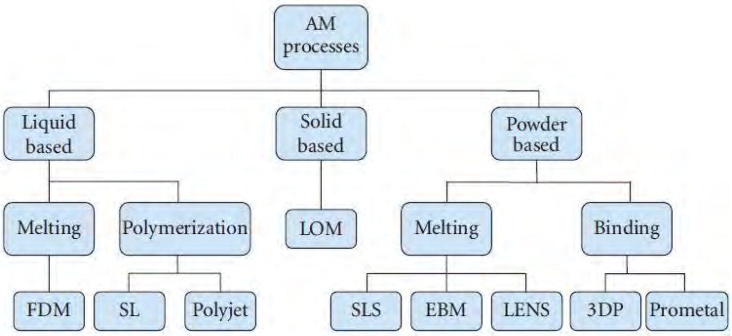

Figure 2.3: Types of Rapid Prototyping Processes (Wong and Hernandez 2012)

2.2 Fused Deposition Modelling (FDM)

2.2.1 Introduction of Fused Deposition Modelling (FDM)

3D printing is affecting daily life in various ways, so do engineer. Engineer will only know the solid physical of CAD design will look until they hold in their hand. It is the only