Faculty of Mechanical Engineering

IMPROVEMENT OF ENGINE BRACKET DESIGN BY USING TOPOLOGY OPTIMIZATION AND ADDITIVE MANUFACTURING

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DECLARATION

I declare that this dissertation entitle “Improvement of Engine Bracket Design by Using Topology Optimization and Additive Manufacturing” is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

Signature	:	……………………
Name	:	……………………
Date	:	………………….....

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Product Design).

Signature	:	……………………
Supervisor Name	:	…………………….
Date	:	………………….....

DEDICATION

To my beloved mother and father

ABSTRACT

Engine bracket plays a crucial part especially in aerospace industry where the mass of bracket affected the performance of aircraft. However, reduction in mass might affected the performance of the bracket. Topology optimization (TO) is a process of optimizing the material by a given design space in response to the set of loads, boundary conditions and constraints in order to maximize the performance. TO result produces complex geometry while additive manufacturing (AM) is a technology to manufacture complex model. The purpose of this study is to obtain a fully optimized lightweight of engine bracket design with capability to withstand the load of the engine by using topology optimization technique. In addition, the effect of manufacturability when incorporating topology optimization in additive manufacturing would also be investigated. In order to minimize the mass and maintaining the stiffness of the bracket, topology optimization by *SolidThinking Inspire* has been applied on two different design spaces which were named by Topology Optimization I (TO I) and Topology Optimization II (TO II). A baseline of target specification on AM outputs which are printing time, raw material mass and support material mass has been obtained by using CreatWare V6.4.3 from a total of 300 existing topology optimized designs of engine bracket from GrabCAD. Remodelling on topology optimized design was done by CATIA V5R20 based on TO and AM constraints in order to fit in the target specification baseline. AM was applied in order to demonstrate the manufacturability for topology optimized design by using Fused Depostion Modelling (FDM) 3D printer with ABS material. In addition, the modification on unsmoothed geometry produced by TO was developed in order to make the design feasible to be manufactured. The result of the study showed the mass of the optimized design was 52% less compared to original design without sacrificing the performance since the von Mises stress of the optimized design was slightly different compare to original design. Based on the study, fabrication of topology optimized design using AM was considered successful but support material was still required for complex geometry produced by TO.

ABSTRAK

Pendakap enjin memainkan peranan penting terutamanya dalam industri aeroangkasa yang mana jisim pendakap mempengaruhi prestasi pesawat. Walau bagaimanapun, pengurangan jisim mungkin menyebabkan prestasi pendakap terjejas. Pengoptimuman topologi (TO) adalah proses mengoptimumkan bahan dalam ruang reka bentuk yang diberi dengan tindak balas kepada set beban, syarat sempadan dan kekangan bagi tujuan memaksimumkan prestasi. TO menghasilkan geometri yang kompleks manakala pembuatan tambahan (AM) adalah teknologi untuk mengehasilkan model yang kompleks. Tujuan kajian ini adalah untuk mendapatkan reka bentuk pendakap enjin ringan yang dioptimumkan sepenuhnya dengan keupayaan menahan beban enjin menggunakan teknik pengoptimuman topologi. Di samping itu, kebolehupayaan pembuatan produk apabila menggabungkan pengoptimuman topologi dalam pembuatan tambahan juga turut dikaji. Untuk meminimumkan jisim dan mengekalkan ketahanan pendakap, pengoptimuman topologi menggunakan SolidThinking Inspire telah digunakan pada dua ruang reka bentuk yang berbeza yang dinamakan Pengoptimuman Topologi I (TO I) dan Pengoptimuman Topologi II (TO II). Spesifikasi sasaran utama pada output AM iaitu masa mencetak, jisim bahan mentah dan jisim bahan sokongan telah diperolehi dengan menggunakan CreatWare V6.4.3 daripada sejumlah 300 buah reka bentuk topologi pendakap enjin yang telah dioptimumkan yang telah diambil daripada GrabCAD. Pengubahsuaian pada reka bentuk topologi yang dioptimumkan telah dilakukan menggunakan CATIA V5R20 berdasarkan kepada kekangan TO dan AM agar sesuai dengan garis panduan spesifikasi sasaran. AM digunakan untuk menunjuk kebolehupayaan pembuatan bagi reka bentuk topologi yang dioptimumkan menggunakan pencetak 3D FDM dengan bahan ABS. Di samping itu, pengubahsuaian pada geometri tidak sempurna yang dihasilkan oleh TO diolah bagi merealisasikan penghasilan reka bentuk tersebut. Hasil kajian menunjukkan jisim reka bentuk yang dioptimumkan adalah 52% kurang berbanding dengan reka bentuk asal tanpa mengorbankan prestasi yang mana perbezaan antara tegasan von Mises bagi reka bentuk yang dioptimumkan adalah sedikit berbeza berbanding tegasan von Mises reka bentuk asal. Berdasarkan kepada kajian ini, reka bentuk topologi yang dioptimalkan menggunakan AM dapat dihasilkan dengan jayanya namun bahan sokongan masih diperlukan untuk menghasilkan geometri kompleks yang dihasilkan menggunakan TO.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

LIST OF ABBREVIATIONS

TO	Topology optimization
AM	Additive manufacturing
FDM	Fused deposition modelling
SL	Stereolithography
LOM	Laminated object manufacturing
SLS	Selective laser sintering
GE	General Electric
STL	Standard Tessellation Language
ABS	Acrylonitrile Butadiene Styrene
PLA	Polylactic acid
STP	Standard for the Exchange of Product
CAD	Computer aided design

LIST OF SYMBOLS

kg	Kilogram
N	Newton
Nm	Newton meter
m	Meter
K	Kelvin
mm	milimeter
MPa	Mega Pascal
GPa	Giga Pascal
^{o}C	Celcius
g	gram
min	minute

CHAPTER 1

INTRODUCTION

1.1 Background

Engine bracket plays a crucial part especially in aerospace industry where the mass of bracket affected the performance and the cost of aircraft. The function of bracket is to hold and to support the weight of the engine during the handling and it stays on the engine all the time. This function makes the bracket as an important and crucial part at the same time. Furthermore, the reduction of mass for bracket which is conventionally made can reduce the fuel cost. Bracket is not the only part on the engine that contributes to high weight but it is one of the parts that offer the opportunity for mass reduction. Optimizing the design for load-carrying mechanical structures is usually related to structural optimization. Bracket is one of the load-carrying mechanical structures that can be optimized by using structural optimization.

There are three categories of structural optimization which are sizing optimization, shape optimization, and topology optimization (Bendsøe and Sigmund, 2003). However, shape optimization has been introduced much longer compare to sizing optimization and topology optimization (TO) (Bendsøe and Kikuchi, 1988). These three categories of optimization have different aspects of the structural design problem to be addressed. The determination of features such as the shape and number and location of holes and the connectivity of the domain is the task involves in the topology optimization for the solid structures.

There are several softwares that can be used in order to generate topology optimized design such as MSC Nastran, Altair OptiStruct, SolidThinking Inspire and others. Each software has different algorithm implemented for different result achieved however to have the same goal. Topology Optimization has a wide range of applications in aerospace, mechanical, bio-chemical and civil engineering. Currently, engineers mostly use TO at the concept level of a design process. The complexity of topology optimized design make the conventional manufacturing process seems impossible. Manufacturing process is difficult due to the free form that naturally occurs. For that reason the result emerging from TO is often fine-tuned for manufacturability. Adding constraints to the formulation in order to increase the manufacturability is an active field of research. TO can helps determine the optimal placement of the material in order to meet design requirements (Bendsøe and Sigmund, 2003). By having optimum material using TO technique, the mechanical properties of the structure can still be maintained. In some cases results from TO can be directly manufactured using additive manufacturing (AM) or known as 3D printing; TO is thus a key part of design for additive manufacturing.

Additive manufacturing (AM) processes enable the production of functional parts with complex geometries, multi-materials as well as individualized mass production. Another significant benefit of AM is the ability to produce optimized geometries with near perfect strength-to-weight ratios. Additive manufacturing has develops into several technologies which are fused deposition modelling (FDM), stereolithography (SL), selective laser sintering (SLS), laminated object manufacturing (LOM) and several more. Different technology has different technique of fabrication in order to suit the requirement needed by part to be fabricated such as binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photopolymerization. An integrated design between topology optimization and additive manufacturing has giving an opportunity to designer in order to produce lighter weight with complex shape as Tomlin and Meyer (2011). By reducing weight of the part the manufacture costs will be less. The volume of the part is proportional to the part cost as in an additive manufacturing process. The more material used, the more expensive the part will be. A320 nacelle hinge bracket made of HC101 steel is optimized from 918g to 326g with reduction of 64% (Tomlin and Meyer, 2011) as shown in Figure 1.1.

For topology optimized design, the stiffness of the part might be changed since the mass has been reduced. However, several studies found that the stiffness of the part gives result of the same or slightly different even the design has changed (Zhu et al., 2013, Rezaie et al., 2013). There are many cases focus on getting lightweight of product for this topology optimization as a result the algorithm will give an output of a lightweight design. However, topology optimization just not reduces the weight but the stiffness of the design also can be maintained.

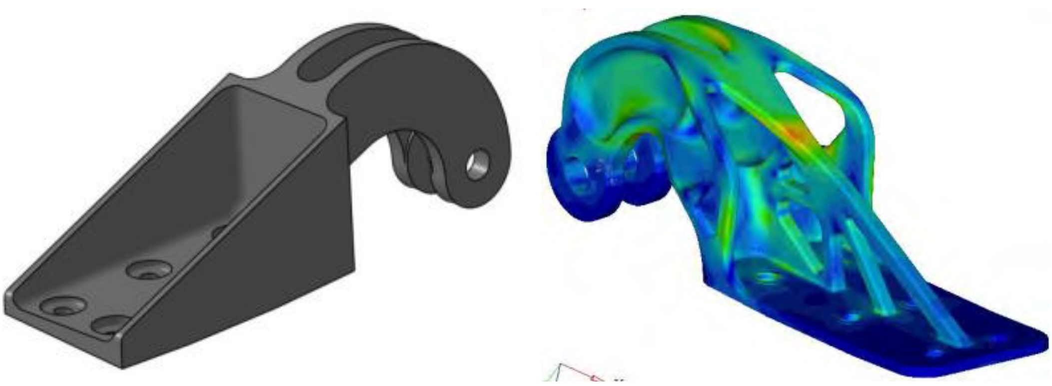

Figure 1.1: Original and optimized hinge bracket (Tomlin and Meyer, 2011)

1.2 Problem Statement

In current era, a light weight part is needed in comparison to heavier part in order to reduce the manufacturing or maintenance cost. Besides that, having part with lighter weight and the same mechanical properties will give benefits especially in aircraft industry since weight play a crucial part in this industry. In order to produce the lighter weight in part, a topology optimization technique should be taken. By using this technique, the mass of the part can be reduced while maintaining its mechanical properties. However, topology optimization technique will provide complicated design in order to fulfill the part requirement after several constraints are applied. Additive manufacturing can be used to fabricate any complex part as it is the new technology used for making any design is possible to be produced.

1.3 Objectives

The objectives of the research are:

i. To obtain a fully optimized lightweight of engine bracket design with capability to withstand the load of the engine by using topology optimization technique.

ii. To redesign topology optimized engine bracket based on target specification baseline in terms of raw material mass, support material mass and printing time needed to be manufactured by additive manufacturing.

iii. To study the effect of manufacturability when incorporating topology optimization in additive manufacturing.