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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

SYNTHESIS OF A SHAPE-CHANGING MECHANISM USING COMPUTER-AIDED ENGINEERING

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Master of Mechanical Engineering

2020

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A thesis submitted
in fulfillment of the requirements for the degree of
Master of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Mechanical Engineering.

Signature : Anuar

Supervisor Name : Dr. Shamsul Anuar Bin Shamsudin

Date : 30/10/20

DEDICATION

I dedicate this work to my only mother, Hjh. Jamaliah Binti Md Noor, and my beloved uncle, Hj. Nordin Bin Md Nor.

ABSTRACT

The research and development of shape-changing technologies continue to grow since it is predicted to revolutionize current technologies. Even today, shape-change technologies have been used in many applications, from large structures such as aircraft wings and to everyday use objects such as toys. Many studies were done on the shape-change materials, the objective is mainly to alter the microstructure of the material so it shape-change when targeted properties (temperature, pressure and etc.) change. Shape-change ability can also be obtained by manipulating the mechanisms. With shape-change technology, it is believed that the overall cost can be reduced then able to preserve the earth wellbeing. This project is to propose a shape-changing mechanism design in an aircraft wing by using actual wing profiles and shape-change coordinate from previous study and analyze the end transformation result. The data obtained is in form of coordinates, is then transferred into a CAD software which is Inventor to begin with CAD modelling and created a solid wing profile with 5 mm thickness and 10 mm wide. From there, the shape-change mechanisms are designed for the CAD wing model. The design objective is to transform E420 wing shape to E850 wing shape. To hold the links together, a connector is designed as a new part. To realize it in an aircraft wing, two design approaches are proposed which are flexural hinges and revolute joints. The comparison of the two design approaches had shown that the flexural hinges suited the best for shape-change purposes, but it will require thorough studies on mathematics, thus, revolute joints design approach is selected for the transformation. It is suggested to do a proper research on flexural hinges especially in obtaining the correct diameter of sectioning. Next, the transformation had been done by manually adjusting the movement in model assemblies due to unsuccessful slider mating in Inventor software for tangential surface. It is suggested to do motion analysis using other software which is more advance in simulation. From the transformation, it was observed that the transformation from E420 to E850 is achievable but was not aligned accordingly to the 2D image canvas and has a total of 19 interferences equals to 6.59e-7 m^3 volume. The transformation was then done separately between the upper and the lower part assemblies and both were able to transform accordingly. From this, it was identified that, the problem is due to the mismatching between the data used. Next, the wing weight is evaluated in its full wingspan of 1.74 m and 0.2 m chord. The weight calculated is 86.06 N for one wing. For a pair of revolute joints wing design, it only consumes 34% total weight of a 500 N UAV. Finally, the DOF calculated for this design is 1, in which it can achieve the required positions with use of one actuator.

SINTESIS MEKANISMA UBAH-BENTUK MENGGUNAKAN KEJURUTERAAN BERBANTU KOMPUTER

ABSTRAK

Penyelidikan dan pengembangan teknologi ubah-bentuk terus berkembang sejak ianya diramalkan boleh merevolusi teknologi terkini. Bahkan pada hari ini, teknologi ubah-bentuk telah digunakan dalam banyak aplikasi, dari struktur besar seperti sayap pesawat sehingga ke objek penggunaan sehari-hari seperti mainan. Banyak kajian telah dilakukan pada bahan ubah-bentuk, tujuannya adalah untuk mengubah struktur mikro bahan untuk berubah bentuk ketika parameter yang disasarkan (suhu, tekanan dan lain-lain) berubah. Keupayaan ubah-bentuk juga dapat diperoleh dengan memanipulasi mekanisma. Dengan teknologi ubah-bentuk, ianya dipercayai bahawa kos keseluruhan dapat dikurangkan dan juga dapat memelihara kesejahteraan bumi. Projek ini adalah untuk memperkenalkan reka bentuk mekanisma ubah-bentuk dalam sayap pesawat menggunakan profil sayap sebenar dan koordinat ubah-bentuk daripada kajian lepas dan seterusnya menganalisis hasil transformasi akhir. Data yang diperoleh adalah dalam bentuk koordinat, ia kemudian dipindahkan ke dalam perisian CAD iaitu Inventor, untuk memulakan pemodelan CAD dan menghasilkan profil sayap padat dengan ketebalan 5 mm dan lebar 10 mm. Dari itu, mekanisma ubah-bentuk direka untuk model sayap CAD tersebut. Objektif reka bentuknya adalah untuk mengubah bentuk sayap E420 menjadi bentuk sayap E850. Untuk menyatukan pautan-pautan, sebuah penyambung direka sebagai bahagian baru. Untuk merealisasikannya di sayap pesawat, dua pendekatan reka bentuk dicadangkan iaitu engsel lentur dan sendi putaran. Mekanisma untuk pendekatan reka bentuk sendi putar dibuat secara berasingan untuk setiap segmen bagi memudahkan proses reka bentuk. Perbandingan antara kedua pendekatan reka bentuk menunjukkan bahawa engsel lenturan paling sesuai untuk tujuan perubahan bentuk, tetapi memerlukan kajian menyeluruh mengenai matematik, oleh itu, pendekatan reka bentuk sendi putaran dipilih untuk transformasi. Dicadangkan supaya, melakukan penyelidikan yang tepat mengenai engsel lenturan terutama dalam mendapatkan diameter pemotongan yang betul. Seterusnya, transformasi telah dilakukan dengan menyesuaikan pergerakan secara manual dalam pemasangan model kerana kawad gelangsar tidak berjaya dihasilkan dalam perisian Inventor bagi permukaan tangensial. Dicadangkan supaya melakukan analisis gerakan menggunakan perisian lain yang lebih maju dalam simulasi. Dari transformasi tersebut, diperhatikan bahawa transformasi dari E420 ke E850 dapat dicapai tetapi tidak selaras dengan kanvas gambar 2D, dan memiliki jumlah 19 gangguan bersamaan dengan 6.59e-7 m^3 isipadu. Transfomasi dilakukan secara terpisah antara pemasangan bahagian atas dan bawah, kedua-duanya dapat mentransformasi dengan sewajarnya. Dari ini, masalah adalah disebabkan oleh ketidaksama antara data yang digunakan. Seterusnya, berat sayap dinilai dalam jarak sayap penuh 1.74 m dan kord 0.2 m. Berat yang dikira ialah 86.06 N untuk satu sayap. Untuk sepasang reka bentuk sayap sendi putar, ia hanya menggunakan 34% berat keseluruhan 500 N UAV. Akhirnya, DOF yang dikira untuk reka bentuk ini adalah 1, di mana ia dapat bergerak kepada semua posisi dengan hanya menggunakan satu penggerak.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform.

My utmost appreciation goes to my main supervisor, Dr. Shamsul Anuar Bin Shamsudin, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered.

Last but not the least, from the bottom of my heart a gratitude to my mother, Hjh. Jamaliah Binti Md Noor, for her encouragements and who have been the pillar of strength in all my endeavors. To my uncle, Nordin Bin Md Nor for all the support and love. I would also like to thank my beloved friends for their endless support, love and prayers. Finally, thank you to all the individual(s) who had provided me the assistance, support and inspiration to embark on my study.

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	-	Two-Dimensional
3D	-	Three-Dimensional
CAD	-	Computer-Aided Design
CAE	-	Computer-Aided Engineering
DOF	-	Degree-of-Freedom
SMA	-	Shape-Memory Alloy
UAV	-	Unmanned aerial vehicle

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CHAPTER 1

INTRODUCTION

1.1 Background

As the technologies around the world is improving and entered the new phase of industrial revolution which is Industry 4.0, researchers are eager to develop new and advance technologies to compromise the technologies demands. A virtual copy of the physical world can be built with the aid of cyber-physical systems which control physical processes. Therefore, these devices are able to make autonomous choices themselves and gain a high degree of autonomy (Industry 4.0, 2020).

Shape-change is not a new subject in engineering field until recently, since 2011, shape-change has become a subject to improve. As the technologies become much better especially in simulations, improving shape-change technologies becomes more possible. Numerous of studies on shape-change has been conducted since then.

Shape-changing mechanism is continue to grow especially in aerial vehicles. Morphing aircraft is aerial vehicle which are capable of changing their wing configurations to achieve the optimal flight performance to accomplish multiple missions. There are growing numbers of research study in morphing wing development to further improve morphing wing performance in all aspects. Previous studies encouraged shape-changing technologies to be applied in morphing wing structures in order to improve their performance and to advance in the technologies (Kota et al., 2003; Roudaut et al., 2013). The design mechanisms also required to include the concerns about binding and friction, range of motion, the control of the actuator stroke under load, and the effects of wing structural deformability under load.

Nevertheless, most of the previous studies are focusing on shape-changing in materials and many had shown that the aerodynamic performance of the aircraft can be improved with shape-changing materials. Musavir et al. (2018) has proposed a new adaptive wing with better performance than variable span using smart material technology.

Tong et al. (2014) has used laminated fiber reinforced composite as a material in topology optimization for wing leading edge to give the device the ability to shape-changing. In another study conducted by Musavir et al. (2018), smart materials included are Shape-Memory Alloy (SMA) technology, piezoelectric actuator and synergetic actuator. And it was claimed that the combination of smart materials and actuators is the main components to the endurance of morphing aircraft, with a significant demand for powerful, lightweight, and compact solutions.

Shape-change is possible to invent using mechanical design. Shamsuddin's (2013) has proven this possible in the research. A closed profile wing that transformed between E420 and E850 airfoils was generated by using piecewise linear curves with segmentation process to create smoother curves in two dimensions (2D). The new shape-changing wing profiles are shown in Figure 1.1 below.

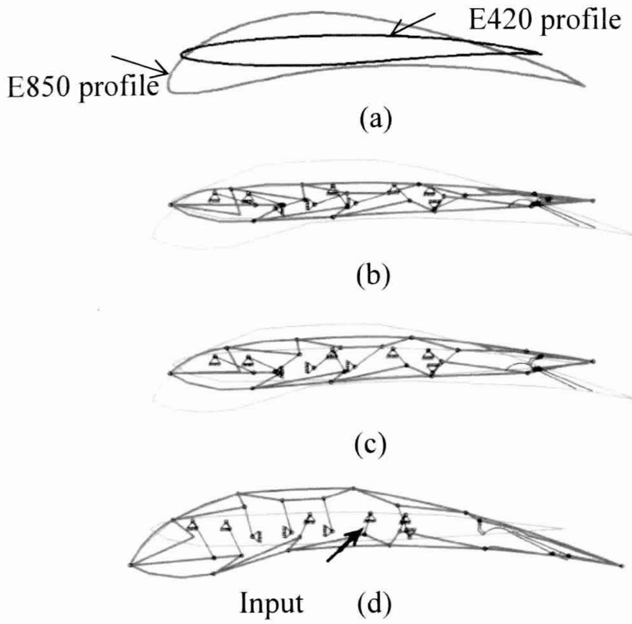

Figure 1.1 Shamsudin (2013) suggestion for a rigid body shape-changing wing.

1.2 Problem Statement

Due to the advancement of smart material technology, researchers are prone to do more research on shape-changing devices using various advance material, in result, less studies were done on synthesizing shape-changing mechanism using mechanical devices. Compared to smart material, mechanical mechanism is easier to manipulate, also, a proper mechanism design may save more cost in terms of time and money since smart material is more on altering the material properties.

Despite extensive research on mechanism design development of shape-changing, it is clear that this area of interest is lacking on mechanism improvement study especially on three-dimensional (3D) design. To include, there are few studies of shape-changing mechanisms of aircraft wing in 2D that proposed the shape-change kinematics and profiles by using mathematical analysis. Shape-change is important to make significant change in technology revolution and it is believed that the overall cost can be reduced and then preserve the earth well being.

From the previous studies on using 2D designing shape-changing device, it were all agreed that this method is less reliable in shape-changing designing due to lack of physical touch and risks when implementing it in actual situation. Also, it was suggested to use high intelligent technology equipment to achieve the shape-changing design (Kota et al., 2003; Joshi et al., 2004; Roudaut et al., 2013). To add, the novel designs and prototypes of shape-change are very little documented (Rasmussen et al., 2012).

Thus, this research will pursue on remodeling the 2D wing shape into 3D model using computer aided-design (CAD) and to apply linkage mechanism to a wing segment to give it the ability to shape-change. Further analysis will be conducted to achieve the purpose of morphing wing in terms of wing transformation and mechanical properties.

1.3 Research Objectives

The aim of this research is to synthesis shape-changing mechanism using CAD and computer-aided engineering (CAE). Thus, the objectives of this research are as follows:

a) To identify the actual wing profiles and their shape-changing coordinate.

b) To design shape-change mechanisms using CAD.

c) To analyze the transformation ability of the shape-change mechanisms.

1.4 Scope of Research

After setting the objective, the scope of this study has been described below and includes the following conditions:

- This study started with identifying the actual wing profiles and their shape-changing coordinates from previous studies.

- The data from previous studies such as coordinates and 2D images are then imported in CAD software to begin with the 3D modelling.
- Two shape-change mechanisms which are flexural hinges and revolute joints approach are designed on the 3D wing profile.
- The end transformation results will be compared with other researcher findings to analyze the transformation ability of the shape-change mechanisms on the 3D models.

1.5 Contribution of Research

Contributions of this thesis are made in the following related areas:

a) The first contribution of this work is in transforming the mathematical data or 2D data into 3D using CAD software.

b) The mechanisms used to give it the ability to transform will be included. Thus, this research will provide information on work relating to shape-changing mechanisms.

1.6 Thesis Outline

In essence, this thesis is oraganized in five (5) chapters, which can be summarized as follows:

- Chapter 1: Introduction. This chapter covers the state-of-the-art of the study, including the research problems, the objectives, the scopes, as well as the importance of the work.

- Chapter 2: Literature review. This chapter starts with brief overview of shape-change concept and devices. A brief summary of shape-change ability, materials, mechanisms and presents various literatures on shape-change machine, also the mathematical modelling used to shape-change is also presented.

- Chapter 3: Methodology. This chapter presents the methods to developed a 3D model of one segment of an aircraft wing using Inventor. It discusses some aspects in the mechanism design.

- Chapter 4: Result and Discussion. This chapter discusses the outcomes from the transformation process using revolute joints mechanism and problems occurred during development process.

- Chapter 5: Conclusion. This chapter concludes all chapters and provide suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The study of shape-change technologies is increasing in number. It is believed that, by advancing the shape-changing mechanisms and atomic microstructure of materials, these technologies are able to replace the current technologies. This chapter provides the discoveries on the shape-changing technologies in vehicles, machinery and general objects such as toys. The most significant findings from previous studies, mathematical theories and modelling are also included in this chapter.

2.2 Shape-Change Ability

The building in shape-changing devices trend is increasing. This type of device is described as device that adapt their shapes on-demand and not static also known as dynamic affordance (Kim et. al., 2018a; Rasmussen et. al., 2012; Roudaut et. al., 2013). Understanding the quality of an object or affordance is significant nowadays, which affordance is defined as the quality of an object to tell us how to use it and to help us in using it (Gibson, 2015).

Rasmussen et al. (2012) has made a review on shape-changing interfaces. In the review it has concluded that, shape-change in an object can be achieved by two methods which are by mechanisms or materials. According to that, shape-change can be in several types which are, orientation, form, volume, texture, viscosity, spatiality, adding/subtracting, and permeability. And the transformation can be in kinematic parameters (velocity, path, direction and space) or expressive parameters (association and adjectives) types of transformation. Moreover, the physical interaction, direct and indirect is needed for the object to shape-changing.

2.2.1 Shape-Changing Materials

Shape-change in materials may be enabled in many conditions such as temperature and pressure that forcing the atomic structures of the materials to move to different phase or place.

A study on morphing wing topology optimization for composite materials was done by Tong et al. (2014). This study used a symmetric laminated plate with orthotropic glass fiber reinforced epoxy as its material and the morphing wing of aircraft F-111 (shown in Figure 2.1). According to Tong et al. (2014), the elastic properties of the material makes it an excellent material to design. To be more specific, the topology optimization was limited to wing leading edge part is due to achieving the better mechanical properties in that particular wing part. In result, the study has approximately achieved the desired shape by using topology optimization model based on SIMP method.

Weisshaar (2006) and Prock, as well as Weisshaar and Crossley (2002) underscored the importance of searching for new technologies to gain improved control surfaces for military aircrafts. They used smart materials to actuate the shape change in the trailing-edge flap of an aircraft wing. Investigation on the use of smart materials like active fiber composites and piezoceramics to morph the shapes of helicopter blades was done by Cesnik et al. (2001), Wong (2007), and Grohmann et al. (2006) due to the reason of many US Military organizations are interested in developing shape-morphing rotor blades (Warwick, 2010). Similar studies were conducted on wind turbine blades by Barlas et al. (2010), Gaunaa (2010), and Lambie (2011). They built-in moving flaps at the leading and trailing edges of the airfoil to change blade shapes related to the speed of the wind. The predicted optimized output achieved by introducing the active flow control of the wind turbine rotors (Maheri et al., 2007 and Weinzierl et al., 2012).

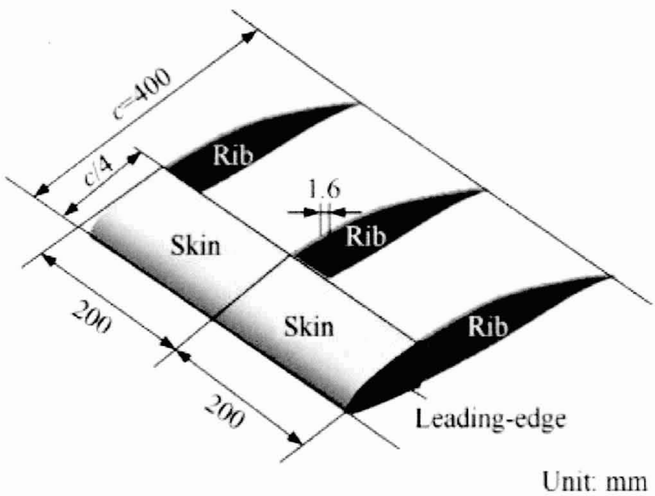

Figure 0.1 Schematic diagram of three consecutive wing ribs (Tong et al., 2014).

2.2.2 Shape-Change Mechanisms For Rigid-body

Zhao et al. (2012) introduced a synthesis technique that able to reduce the complex mechanical structures in a main body of wing by defining some part of the morphing surface as fixed to the ground means that the part has minimal displacement after segmentation process. To obtain a 1 degree-of-freedom (DOF) mechanism, the researchers proposed a building-block technique that include prismatic joints. That work also proposed a weighted least squares method to get the best representation of the morphing profiles and numerical optimization method to locate the best position of building-blocks on the segment of profiles.

In a previous study by Shamsudin et al. (2013), three planar shape-change wing profiles were used. The chain of the wing sections that changed their shapes that are