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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

STRUCTURAL ANALYSIS OF SHAPE-MORPHING AIRCRAFT SLAT BY USING FINITE ELEMENT ANALYSIS

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Master of Mechanical Engineering (Applied Mechanics)

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STRUCTURAL ANALYSIS OF SHAPE-MORPHING AIRCRAFT SLAT BY USING FINITE ELEMENT ANALYSIS

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A dissertation submitted
In fulfillment of the requirements for the degree of Master of Mechanical Engineering (Applied Mechanics)

Faculty of Mechanical Engineering

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2016

DECLARATION

I declare that this dissertation entitled "STRUCTURAL ANALYSIS OF SHAPE-MORPHING AIRCRAFT SLAT BY USING FINITE ELEMENT ANALYSIS" 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 the candidature of any other degree.

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APPROVAL

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

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Supervisor Name : DR. SHAMSUL ANUAR BIN SHAMSUDIN

Date : 31/10/2016

DEDICATION

This dissertation work is dedicated to my Parents. My father (Ali Hassan), you have always been an inspiration to me. You set a great example for me. When I think back of the sacrifices you made, then I know that you gave the most precious gift for me.

Also to my mother, who puts up with me for all these years. Throughout the years, you have always been there by my side. I can face anything with you by my side.

My wife, who has supported and encouraged me. You have been so creative. You give a lot, and I appreciate how much you have given.

For my brothers and my sister, and my big family, I ask Allah to protect you all. You are good examples that taught me to work hard for the things that I aspire to achieve.

ABSTRACT

The changing of the wing shapes on an aircraft always amazes many people especially those in the flights. The field of shape morphing aircraft has attracted the attention of many research groups during the past century. Although many interesting concepts have been synthesized, only a handful involves the shape morphing slat for aircraft wing. The aerodynamic pressure of the morphing slat structure could lead to failure or structural damage, probably stemming from the basic design or the result of the failure seen in the material used for the structure's manufacturing. The purpose of this research is to analyze the new generation of aircraft morphing slat, by utilizing a Finite Element (FE) model as a design tool to assess the structural integrity of structure of the new morphing slat. Another aim is to investigate a material deemed suitable for making the morphing slat that can result in less deformation and stresses. In this study, structural analyses were carried out by using ANSYS WORKBENCH on the morphing slat geometry after creating it in CATIA V5. In a structural analysis, the modeling used three different materials, namely, Al6065-T6, AA7075-T651, and GFRP. The structure of morphing slat is subject to maximum aerodynamic pressure in two flight phases that include taking-off and landing which was found by using Computational-Fluid Dynamics (CFD) analysis from earlier work. By conducting the structural analysis, one can examine the reliability of the rigid segments and structure of morphing slat under the applied aerodynamic load, which is necessary for the selection of the material for the morphing slat design. The results of static structural analysis showed that the AA7075-T651material is the most suitable material that can be used for morphing slats because it has the least deformation and strain after comparing it with Al6065-T6 and GFRP. Hence, AA7075-T651 can give the structure of morphing slat more strength over the other two materials.

ABSTRAK

Penukaran bentuk sayap pesawat terbang sentiasa menarik minat ramai orang terutamanya semasa menaiki penerbangan. Bidang pesawat terbang yang berubah bentuk telah menarik minat banyak kumpulan penyelidik sejak seabad yang lalu. Walaupun ada pelbagai konsep yang disintesis, hanya sejumlah kecil melibatkan slat sayap pesawat terbang yang berubah bentuk. Justeru, tujuan disertasi ini adalah untuk menganalisis generasi baharu slat yang boleh berubah bentuk. Dengan menggunakan model unsur terhingga (FE) sebagai alat rekabentuk, integriti struktur slat pesawat yang baharu ini telah dapat dinilai. Satu lagi objektif kajian adalah untuk mencadangkan bahan yang sesuai untuk digunakan dalam pembuatan slat sayap tersebut. Ia perlulah kepada satu bahan yang menghasilkan anjakan paling kecil dan tegasan yang rendah. Dalam kajian ini juga, Analisis Unsur Terhingga (FEA) dilaksanakan dengan aplikasi ANSYS WORKBENCH. Pada keseluruhannya, tiga bahan digunakan iaitu Al6065-T6, AA7075-T651, dan GFRP. Struktur slat yang berubah bentuk tertakluk kepada tekanan aerodinamik maksimum dalam dua fasa penerbangan itu termasuk tekanan semasa berlepas dan mendarat yang didapati melalui Dinamik Bendalir Berkomputer (CFD) yang dilaksanakan dalam kajian terdahulu. Dengan menjalankan analisis struktur, penyelidik dapat memeriksa kebolehpercayaan segmen tegar di bawah beban aerodinamik yang dialami semasa penerbangan. Seterusnya adalah untuk menilai bahan yang sesuai dalam rekabentuk sayap berubah bentuk. Keputusan kajian FEA telah menunjukkan bahawa bahan AA7075-T651 adalah bahan terbaik yang boleh digunakan untuk slat berubah bentuk kerana ia mempunyai anjakan yang paling kecil dan tegasan paling rendah selepas dibandingkan dengan bahan-bahan lain. Justeru, ia boleh memberi kekuatan yang lebih tinggi daripada dua bahan lain tersebut.

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LIST OF ABBREVIATIONS

3D	three-dimensional
GFRP	Glass Fiber Reinforced Polymer
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
mm	millimeters
MPa	Mega Pascal
N	Newton
Nm	Newton meter

LIST OF SYMBOLS

F	-	Force
ν	-	Poisson's ratio
E	-	Young's modulus
m	-	Mobility joints
n	-	Number of elements
J_1	-	Lower-order pair joints
ε	-	Strain
R	-	Radius
L	-	Length

CHAPTER 1

INTRODUCTION

1.1 Background

Aircraft wings enable the aircraft to fly at a range of flight conditions, but it is found out that the performance at each condition is below the optimal level. Over the years, the wing surface's ability to change its geometry during flight has fascinated researchers and designers as this diminishes the design compromises required. The short form for metamorphosing is morphing; however, it has no real definition or even a consensus among the researchers about the type or the extent of the geometrical changes that are needed to qualify an aircraft under the label 'shape morphing.' Geometrical parameters that can be impacted by morphing solutions can be sorted into several states the platform alteration (span, sweep, and chord), out- of plane transformation (twist, dihedral/gull, and span-wise bending), and airfoil adjustment (camber and thickness). Altering the wing shape or geometry is not new morphing solutions – often it will lead to shortcomings involving the cost, complexity, or weight, although in some occasions, these were solved with the help of the system-level benefits. The current trend for extremely efficient and 'green' aircraft makes such compromises less tolerable, calling for more modern morphing designs which are able to offer more benefits and lesser drawbacks. Recent developments in 'smart' materials may be able to address the limitations and improve the benefits from the readily available design solutions.

High-lift systems in Figure 1.1 (slats and flaps) have an important role in aircraft performance, and their use is evident during takeoff and landing. While they have a crucial role to play, conventional high-lift systems are not devoid of some issues that affect the aircraft performance. First of all, a high-lift system is a part of a multi-element airfoil with three elements; one element serves as the main body, and two elements are the high-lift systems. There were assertions in previous works that the high-lift systems and landing gears have proven to be the main noise producing components of airframe noise (Hayes, 1997).

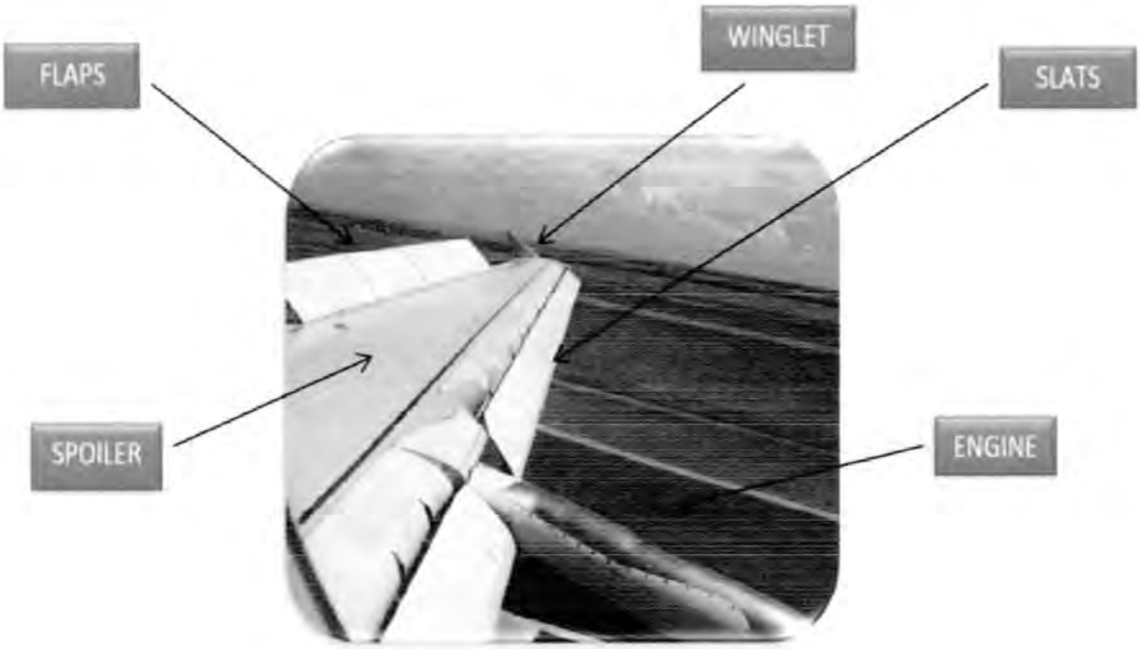

Figure 1.1 Aircraft slat and flap (Sahin, 2012)

To solve the issues on the high-lift systems, some actions can be carried out. Using a shape-changing mechanism on aircraft wing that uses rigid-body segments that form a closed-chain connected by revolute joints removing the gap between the main components could well be one of them. Reseracher are recommended and developed some shape-changing mechanisms that pay attention to the slat of 30P30N airfoil (Zhao, 2012).

There is a great influence of the high-lift systems towards the sizing, economics, and safety of most transport airplane configurations. The complexity emerging in flow physics, geometry, and system support and actuation did contribute to a lengthy and experiment intensive development process. Nonetheless, the previous engineering design has changed significantly causing exponential developments in computational hardware and software. In the aerodynamic design, computational methods are gradually overriding the empirical methods and design engineers are dedicating more of their time applying computational tools rather than embarking on physical experiments to design and analyze aircraft which also include the high-lift systems.

1.2 Problem Statement

The structure for the morphing slats of the wing is subject to various types of loads in each flight phase, and these include the take-off, cruise, and landing. In each segment, there is a variation in load factor which triggers multiple stresses in the components of leading edge slats. In this study, the mechanism involves a novel slat design. There are various types of stresses and its intensity induced in the leading edge slat of the aircraft wing during take-off and landing of an airplane flying through the new shape morphing slat design for the leading edge slat.

Stresses that emerge out of the aerodynamic pressure of the morphing slat structure could lead to failure or structure damage, probably stemming from the basic design or the result of the failure seen in the material used for the structure's manufacturing.

1.3 Objective of research

1. To develop a Finite Element (FE) model as a design tool to access the structural integrity of structural analysis for the new morphing slat.
2. To investigate materials that are deemed suitable for making the morphing slat that can give less deformation and strain in the morphing slat of the aircraft wing.

1.4 Scope of work

This work implements the analysis with ANSYS WORKBENCH by using static structural analysis to get the stresses, strain and deformation in the morphing slat. The geometry will be created by CATIA V5 the import to ANSYS WORKBENCH. We will consider three materials that are commonly used for wing section in aircraft manufacturing or used before in leading edge slat. The materials are AA7075-T651, Al 6065-T6 and GFRP. In structural analysis aerodynamic force will be the maximum pressure has been found by using CFD analysis on morphing slat in two cases landing and takeoff. From structural analysis result we use deformation and strain to compare between these materials. The material that produces the least deformation and strain will be considered the most suitable to use for the morphing slat.

1.5 Dissertation outline

Besides Chapter One, there are four more chapters in this dissertation. There are described as follows.

Chapter Two delves into the fundamental characteristics of a morphing wing and high lift device (slat and flap). The works and findings of the other academia regarding the concept of the morphing wing will also be discussed. Chapter Three reviews the approach that will be used to reach the final result. The structural analysis of morphing slat and what is materials can be used for morphing slat.

Chapter Four presents the result of this study which is the discussions of the structural analysis results. The findings for two status (landing and takeoff) devised based on the objectives defined in the earlier section will be discussed thoroughly and the significance will be established later. Chapter Five offers a conclusion of this study via some concluding statements and findings through the FEA result and give some recommendation for futureworks.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The development of a wing that will be able to accomplish contradictory missions such as the observed changes in wing shape is the goal embedded in the morphing wing research. In general, long and thick wing shapes are highly appropriate for slow, gliding flight while short, thin, swept wings enable quick maneuvering. One can negotiate on choosing his own wing, allowing for each of the aircraft's intended missions to show the best performance. Changing the shape of the wing during its missions brings the wing performance closer to the ideal for each task assigned to it (Barbarino, 2011).

An aircraft with a morph-able wing will demonstrate a better performance for a far wider variety of missions. It will have the versatility to carry out contradictory mission objectives in an efficient manner and the adaptability to complete unforeseen tasks(Butt, 2005). Another aspect of a morph-able wing is its ability to control the roll, pitch, and yaw without requiring the ailerons and elevators. The elimination of these parts has the potential to increase the reliability and reduce wing maintenance. Another substantial factor in their elimination is the removal of seams along the wing. This brings about greater fuel efficiency by decreasing drag and lowering the total aircraft weight

The arduous task is to design a structure that is capable of withstanding the prescribed loads, but is also able to alter its shape: Ideally, there should be no difference between the structure and the actuation system.