UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

MODELING AND ANALYSIS OF COMPOSITE HINGE FOR AIRCRAFT SPOILER USING FINITE ELEMENT ANALYSIS

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Master of Science in Mechanical Engineering

2014

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

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

DECLARATION

I declare that this thesis entitle "Modeling and Analysis of Composite Hinge for Aircraft Spoiler using Finite Element Analysis" 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	:	WAI CHEE MUN
Date	:	....

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Science in Mechanical Engineering.

Signature : …………………………........

Supervisor Name : AHMAD RIVAI

Date : ……………………………

DEDICATION

To my beloved parents and dear friends

ABSTRACT

This thesis is concerned with the modeling and analysis of a composite hinge bracket for Airbus A320 aircraft using Finite Element Method. The increasing demand of composite materials in aircraft structural design is due to the high strength and stiffness to weight ratio of the composite materials. The reduction in structural weight by the composite materials reduces the fuel consumption of the aircraft. Since the hinge bracket of the A320 aircraft is made of metallic materials, this research aims to redesign the hinge bracket with laminated composite plates. However, the design of structures with composites is not as easy as the design of metallic structures. Composites are heterogeneous and anisotropic in nature thus, complicating the structural analysis. The best practice of laminated composite design in the industry is simplified to accommodate the limitation of this research. The simplified design process is a simple three stages design process which focused on using Finite Element Anlysis for unidirectional laminated composite structural design. It begins with the determination of stress distribution in a metallic structure. The stress distribution allows the designer to identify areas of different stress distribution of the structure. Once the areas are identified, the direction of principle stresses is determine to decide on the fiber orientation and stacking sequence of the composite laminates for each area. Finally, the analysis of the laminated composite structure is carried out using Classical Laminate Plate theory and the structural integrity is accessed by the calculation of margin of safety. The simplified design process has been applied to redesign the metallic hinge bracket of A320 aircraft using IM7/8552 composite laminates. MSC Patran/Nastran and Abaqus CAE were used to carry out the finite element analysis of the hinge bracket. The composite hinge bracket has a margin of safety of 0.041. The weight savings by this composite hinge bracket is estimated to be 42.29 percent of the original metallic hinge bracket of A320. The success of this composite hinge design has proven that the simplified design process proposed in this research is indeed feasible for the purpose of preliminary design of laminated composite structures. The advantage of this simplified design process is that it approaches the design of composite structures in a systematic manner thus, allowing the identification of factors influencing the strength the laminated composite structural design. Since it is based on Finite Element Method, the results are at best approximations but sufficient to boost the level of confidence in the preliminary design stage.

ABSTRAK

Tesis ini adalah berkenaan dengan pemodelan dan analisis pendakap engsel komposit untuk pesawat Airbus A320 dengan menggunakan Kaedah Unsur Terhingga. Permintaan yang semakin meningkat daripada bahan komposit dalam reka bentuk struktur pesawat adalah disebabkan nisbah kekuatan dan kekakuan kepada berat bahan komposit yang tinggi. Pengurangan berat struktur oleh bahan-bahan komposit mampu mengurangkan penggunaan bahan api pesawat. Penyelidikan ini bertujuan untuk mereka bentuk semula pendakap engsel pesawat A320 dengan menggunakan plat komposit berlapis untuk menggantikan pendakap engsel lama pesawat A320 yang diperbuat daripada bahan logam. Walau bagaimanapun, reka bentuk struktur komposit tidak semudah reka bentuk struktur logam. Sifat bahan komposit yang anisotropik merumitkan analisis struktur. Amalan terbaik reka bentuk komposit berlapis dalam industri dipermudahkan untuk menampung had kajian ini. Proses reka bentuk yang dipermudahkan terdiri daripade tiga peringkat asas yang memberi tumpuan kepada menggunakan Analysis Unsur Terhingga untuk mereka bentuk struktur daripada plat komposit berlapis satu arah.. Ia bermula dengan penentuan agihan tegasan dalam struktur logam. Agihan tegasan membolehkan pereka mengenal pasti kawasan agihan tegasan yang berbeza dalam struktur. Sebaik sahaja kawasan dikenal pasti, arah tegasan prinsip digunakan untuk menentukan orientasi gentian dan susunan urutans lapisan komposit bagi setiap kawasan. Akhir sekali, analisis struktur komposit berlapis dijalankan dengan menggunakan teori Klasik lamina Plat dan integriti struktur diukur melalui pengiraan margin keselamatan. Proses reka bentuk yang dipermudahkan telah digunakan untuk mereka bentuk semula pendakap engsel logam pesawat A320 dengan menggunakan IM7/8552 komposit berlapis. MSC Patran/Nastran dan Abaqus CAE telah digunakan untuk menjalankan analisis unsur terhingga pendakap engsel tersebut. Pendakap engsel komposit mempunyai margin keselamatan 0.041. Penjimatan berat badan oleh pendakap engsel komposit ini dianggarkan 42.29 peratus daripada berat badan asal pendakap engsel logan pesawat A320. Kejayaan reka bentuk engsel komposit ini telah membuktikan bahawa proses reka bentuk yang mudah yang dicadangkan dalam kajian ini memang boleh digunakan untuk tujuan reka bentuk awal struktur komposit berlapis. Kelebihan model ini ialah ia membolehkan pengenalpastian faktor yang mempengaruhi kekuatan reka bentuk struktur komposit berlapis dalam proses reka bentuk struktur. Memandangkan ia adalah satu kaedah berdasarkan Kaedah Unsur Terhingga, keputusan analysis merupakan satu anggaran sahaja tetapi cukup untuk meningkatkan tahap keyakinan dalam reka bentuk dan pembuatan komposit.

ACKNOWLEDGEMENTS

I would like to thank Centre for Research and Innovation Management (CRIM) and Faculty of Mechanical Engineering (FKM) Universiti Teknikal Malaysia Melaka for funding this research through PJP/2012/FKM(18C)S1112 Research Fund and having interest in this area of engineering. I hope that the contents of this thesis can benefit them in designing and developing laminated composite structures in the future.

I would like to extend my appreciation to my supervisors, Associate Professor Ahmad Rivai and Mr Omar Bapokutty, for their suggestions and guidance. Thank you, Mr. Omar, for willing to join my research at a late notice.

I would also like to thank my parents, family members, friends who were involved directly or indirectly in the completion of my thesis. Thank you for your morale support throughout my graduate studies.

Last but not least, I would like to thank God for answering my prayers in my darkest time. The completion of this thesis would not been possible without God’s will. I humbly thank you for guiding and instilling faith in me.

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LIST OF ABBREVIATIONS

1D	-	One dimensional
2D	-	Two dimensional
3D	-	Three dimensional
ASM	-	American Society for Metals
ASME	-	American Society of Mechanical Engineers
CAD	-	Computer Aided Design
CAM	-	Cylindrical Assemblage Model
CLT	-	Classical Laminate Theory
cm^3	-	Centimeter cube
DoFs	-	Degree of Freedoms
DTA	-	Damage Tolerance Analysis
etc.	-	et cetera
FAA	-	Federal Aviation Administration
FACC	-	Fischer Advanced Composite Components
FE	-	Finite Element
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
FPF	-	First ply failure
FRP	-	Fiber Reinforced Polymer
FS	-	Factor of Safety

g	-	Gram
g/cm^3	-	Gram per centimeter cube
GUI	-	Graphic-user interface
IBC	-	International Building Code
in	-	Inch
lb/in	-	Pounds per square inch
mm	-	millimeters
mm^2	-	millimeters square
mm^3	-	millimeters cube
MPa	-	MegaPascal
MS	-	Margin of Safety
Msi	-	Megapounds per square inch
N	-	Newton
Nm	-	Newton meter
NASA	-	The National Aeronautics and Space Administration
PLM	-	Patran Laminate Modeler
PPF	-	Progressive ply failure
psi	-	Pounds per square inch
RBE	-	Rigid Body Elements
RF	-	Reserved Factor
RTM	-	Resin transfer moulding
UD	-	Unidirectional
VAC	-	Volvo Aero Corporation
V&V	-	Verification and validation
VV&A	-	Verification, validation and accreditation

LIST OF SYMBOLS

%	-	Percent
°	-	Degree
cm^3	-	Centimeter cube
g/cm^3	-	Gram per centimeter cube
Ө	-	Angle
V_f	-	Fiber volume fraction
V_m	-	Matrix volume fraction
W_f	-	Fiber weight fraction
W_m	-	Matrix weight fraction
P	-	Density
ρ_c	-	Lamina density
ρ_f	-	Fiber density
ρ_m	-	Matrix density
E_1	-	Lamina longitudinal modulus
E_f	-	Fiber elastic modulus
E_m	-	Matrix elastic modulus
v_{12}	-	In-plane Poisson's ratio
v_f	-	Fiber Poisson's ratio
v_m	-	Matrix Poisson's ratio
E_2	-	Lamina transverse modulus

ζ	-	Empirical parameter
G_{12}	-	Lamina in-plane shear modulus
G_f	-	Fiber shear modulus
G_m	-	Matrix shear modulus.
G_{23}	-	Lamina out of plane shear modulus
σ_1	-	Maximum local stress along fiber direction
σ_2	-	Maximum local stress transverse to the fiber direction
τ_{12}	-	Maximum shear stress in the principal material direction
F_{ft}	-	Fiber tensile strength
F_{1c}	-	Lamina longitudinal compressive strength
F_{2t}	-	Lamina transverse tensile strength
F_{mt}	-	Matrix tensile strength
F_{2c}	-	Lamina transverse compressive strength
F_{mc}	-	Matrix compressive strength
F_6	-	Lamina in-plane shear strength
F_{ms}	-	Matrix shear strength
α_σ	-	Standard deviation of fiber misalignment
V_v	-	Void volume fraction
Π	-	A constant with the value of 3.142

LIST OF PUBLICATIONS

Journal:

Putra, A., Rivai, A., Wai, C.M., and Muhammad, N., 2014. Preliminary Investigation on the Perforated Panel Mobility using Finite Element Method. *Applied Mechanics and Materials*, 471, pp.341 – 346.

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Wai, C.M., Ahmad, R., and Omar, B., 2013. Design and Analysis of an Aircraft Composite Hinge Bracket using Finite Element Approach. *Applied Mechanics and Materials* (Accepted manuscript).

Putra, A., Cheah, Y.M., Muhammad, N., Rivai, A., and Wai, C.M., 2014. The Effect of Perforation on the Dynamics of a Flexible Panel. *Advances in Acoustic and Vibration* (Accepted manuscript).

CHAPTER 1

INTRODUCTION

1.1 Background

Commercial aircrafts, such as Airbus A380 and Boeing E787, have spoilers attached to the top surface of their wings. Spoilers are plate like structures used to assist the landing and descending of an aircraft from higher to lower altitude as well as generate rolling motion of the aircraft (Dawson, 2006; NASA, 2010). Figure 1.1 shows the rolling motion generated by deploying the right spoiler of an aircraft.

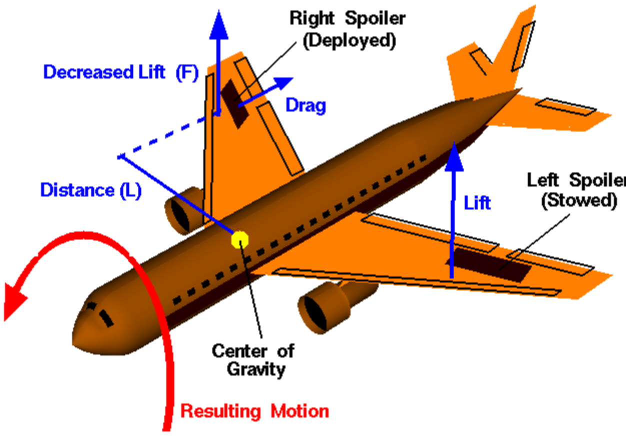

Figure 1.1 : Rolling Motion Cause by Deploying Right Spoiler (NASA, 2010)

As the name suggest, aircraft spoilers are used to “spoil” the airflow over the wing. When both the spoilers are deployed, the drag increases while the lift decreases (Dawson, 2006). The decrease in the lift enables the aircraft to descend from a higher to lower altitude and slow down before landing. Spoilers are also useful in assisting the breaking of the aircraft on the runway (NASA, 2010).

The upward and downward movements of the aircraft spoilers are made possible by a set of hinges. A hinge is a mechanism which allows the rotational motion in one axis (Leet et al., 2008). Hinges usually consists of two brackets. Some hinges have bearings fitting to reduce frictional force between the pin and two brackets. The brackets of the hinges are supportive structures which are usually made of metals. In 2006, Fischer Advanced Composite Components (FACC) AG successfully designed a composite center hinge fitting for Airbus, shown in Figure 1.2, by using resin transfer molding (RTM). The composite hinge is said to be able to withstand 20 ton air load and save 25 percent in weight per set of hinge (Dawson, 2006).

Figure 1.2 : FACC Carbon Composite Center Hinge Fitting (Dawson, 2006): (a) Metal Bushings and Bearings Installed in the Fitting Lugs; (b) Hinge Fitting Molded via RTM

In aircraft construction, composites are more commonly used for secondary structure, wings, fuselages, and even smaller parts such as spoilers (Dawson, 2006). However, the use of composite materials in commercial aircraft has been increasing exponentially since the last decade due to their capability in reducing the overall structural weight of the aircraft effectively (Basavaraju, 2005; Mallick, 2007). Companies such as Airbus and Boeing have been replacing their metallic aircraft parts with composite materials. Figure 1.3 shows the composite structural weight development in Airbus commercial aircrafts. Though the development of composites has mostly been derived from military and The National Aeronautics and Space Administration (NASA) prototypes (Cole, 2002), it is not too farfetch to say that there will be an all composite aircraft one day.

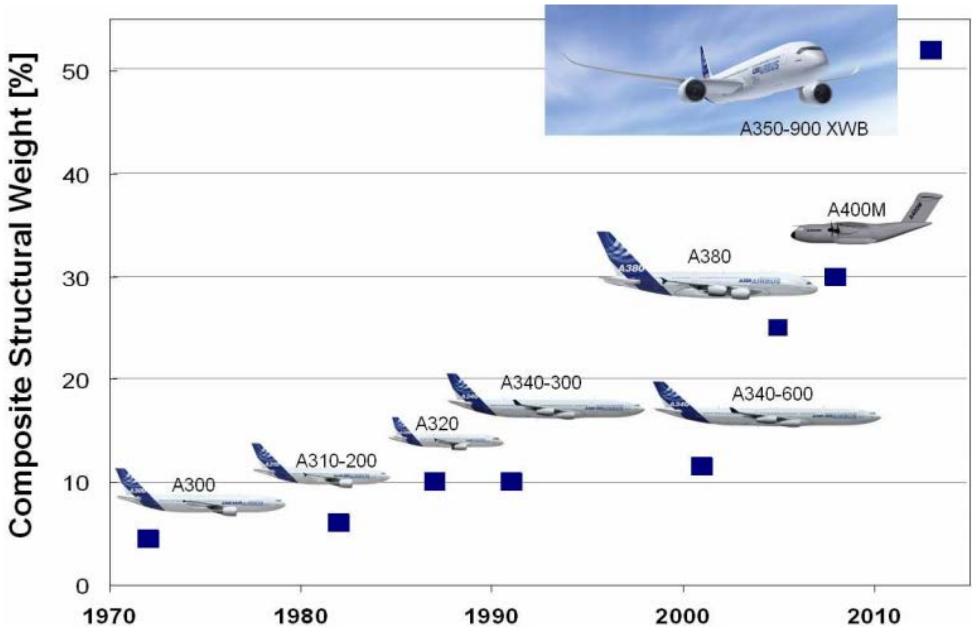

Figure 1.3 : Composite Structural Weight Development in Airbus (Bold, 2007)

1.2 Problem Statement

Existing hinges for aircraft spoilers, especially the old aircraft models, are mostly made of metals. For example, the Airbus A320 aircraft spoiler hinges are still made of metal. The replacement of the existing metallic hinges with composite materials may save up quite a considerable amount of the hinges structural weight. The decrease in the aircraft structural weight will reduce the fuel consumption of the aircraft. However, composite is still considered new compared to the well established monolithic metals (Maligno, 2007; Nguyen, 2010). Therefore, more information and a different approach to design composite structure are required (Mallick, 2007). The industry has developed their own best practices to design composite structures but the educational model flow to design composite structures, especially laminated composite structures, is still lacking in the engineering textbooks.