UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A NEW COMPOSITE ENERGY-ABSORBER SYSTEM FOR AIRCRAFT AND HELICOPTER SUB-FLOORS

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

September 2005

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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September 2005

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Considerable research interest has been directed towards the use of composite for crashworthiness applications, because they can be designed to provide impact energy absorption capabilities which are superior to those of metals when compared on weight basis. The use of composite parts in structural and semi-structure applications is becoming more widespread throughout the automotives, aircraft and space vehicles.

In this study, an innovative lightweight composite energy-absorbing keel beam system has been developed to be retrofitted in aircraft and helicopter in order to improve their

crashworthiness performance. The developed system consists of everting stringer and keel beam. The sub floor seat rails were designed as everting stringer to guide and control the failure mechanisms at pre-crush and post crush failure stages of composite keel beam webs and core. Polyurethane foam was employed to fill the core of the beam to eliminate any hypothesis of global buckling. The numerical prediction was obtained using commercially available finite element analysis software. The experimental data are correlated with predictions from finite element model and analytical solution. An acceptable agreement between the experimental and computational results was obtained. For all structures considered classical axial collapse eigen values were computed.

The results showed that the crushing behaviour of the developed system is found to be sensitive to the change in keel beam core cross-section. Laminate sequence has a significant influence on the failure mode types, average crush loads and energy absorption capability of composite keel beam. The desired energy absorbing mechanism revealed that the innovated system can be used for aircraft and helicopter and meet the requirements, together with substantial weight saving.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM KOMPOSIT PENYERAPAN TENAGA BARU UNTUK SUB-TAPAK KAPALTERBANG DAN HELIKOPTER

Oleh

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September 2005

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Banyak kajian telah dijalankan dalam penggunaan komposit untuk kajian 'crashworthiness' kerana komposit boleh direkabentuk untuk kebolehan penyerapan tenaga yang lebih tinggi jika dibandingkan dengan logam berasaskan berat. Penggunaan tiub bulat komposit dalam applikasi struktur dan semi-struktur semakin tersebar dalam industri automotif, pesawat dan kapal angkasa.

Dalam kajian ini, sistem penyerapan tenaga alur lunas ringan yang inovatif telah dihasilkan untuk pemasangan dalam pesawat dan helikopter bertujuan untuk

memperbaiki prestasi 'crashworthiness'. Gelegar, everting membentuk rel duduk sublantai bertujuan untuk membimbing dan mengawal mekanisma kegagalan pada web dan teras alur lunas komposit di tahap kegagalan pra-hancur dan selepas hancur. Polyurethane digunakan untuk membentuk teras alur tersebut agar lengkokan global dapat dihindarkan. Jangkaan numerikal diperolehi melalui perisian unsur terhingga komersil. Korelasi data eksperimen dengan data dari numerikal dan analitik dilakukan dan didapati ada persetujuan antara kedua-dua data eksperimen dan pengkomputeran. Nilai eigen runtuh sepaksi klasikal dikirakan untuk semua struktur yang dipertimbangkan.

Hasil menunjukkan bahawa kelakuan penghancuran sistem yang dibina adalah peka terhadap perubahan keratan rentas teras alur lunas. Susunan lamina memberi kesan terhadap jenis mod kegagalan, beban purata hancur dan kebolehan penyerapan tenaga alur lunas komposit. Mekanisma penyerapan tenaga terhasil membuktikan bahawa system inovatif ini boleh digunakan untuk pesawat dan helikopter serta memenuhi semua keperluan disamping menjimatkan berat.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and deep thanks to my supervisor Dr. El-Sadig Mahdi Ahmed Saad for his kind assistance, support, advice, encouragement and suggestions throughout this work and during the preparation of this thesis.

A particular note of thanks is also given to the Prof. Dr. Fakhrul-Razi Ahmedun for his suggestions and financial support and members of supervisory committee Dr. Ahmad Samsuri Mokhtar and Mrs. Dayang Laila Abg Abdol Majid for their suggestions and constructive criticisms given at different stages of this study.

Finally, I would like to express my indebtedness to my family for their moral and financial support.

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NOMENCLATURE

Parameter	Definition	Unit
a	Height of plate	mm
a/b	Plate aspect ratio	mm/mm
A	Cross-sectional area	mm^2
A_{ij}	Elements of extensional stiffness matrix (ij= 1, 2, 6)	N/m
b	Width of plate	mm
B_{ij}	Elements of coupling stiffness matrix (ij= 1, 2, 6)	N
CFE	Crush force efficiency	N/N
C	Clamp support	
Cn	Clamp support on n^{th} side of plate (n=1…4)	
c	Clamp support	
D_{ij}	Elements of bending stiffness matrix (ij= 1, 2, 6)	N.m
δ_p	Post crush displacement	mm
E	Young's Modulus	GPa
E_T	Total energy absorbed	kJ
E_{11}	Longitudinal Young's Modulus (direction-1)	GPa
E_{22}	Transverse Young's Modulus (direction-2)	GPa
E_s	Specific energy absorbed	kJ/kg
ε_x, ε_y, ε_z	Strain in x, y and z directions respectively	mm/mm
FR	Foam ratio	m^3/m^3
Fx, Fy, Fz	Forces in x, y and z directions respectively	kN
G_{12}	In-plane Shear Modulus (in the 1-2 Planes)	GPa
H	Thickness of laminate	mm
k_x, k_y, k_z	Curvatures in x, y and z directions respectively	1/m
l	Length of the part	mm
M	Mass	kg
m	Number of buckle half wavelengths (in x-direction)	
M_x, M_y, M_z	Moments resultant in x, y and z directions respectively	N.m
M_{xy}	Moment resultant in xy-plane	N.m
n	Number of buckle half wavelengths (in y-direction)	
$\bar{N}_x, \bar{N}_y, \bar{N}_z$	Stress resultant in x, y and z directions respectively	N/m
$\bar{N}_{xy}$	Shear force resultant	N/m
P_i	Initial crushing load	kN
$\bar{P}$	Average crushing load	kN
Q_{ij}	Elements of reduced stiffnesses matrix (ij=1, 2, 6)	GPa
$\bar{Q}_{ij}$	Elements of transformed reduced stiffness matrix (ij= 1, 2, 6)	GPa
r	Radius of everting groove	mm
S	Simple support	
SE	Stroke efficiency	
Sn	Simple support on n^{th} side of plate (n=1…4)	
s	Simple support	

u	Displacement (in x-direction)	mm
V	Volume	m^3
v	Displacement (in y-direction)	mm
ν_{12}	Poisson's ratio (in the 1-2 Planes)	
V_f	Volume fraction of fibre	
V_r	Volume fraction of matrix	
w	Displacement (in z-direction)	mm
W_f	Weight of fibre	kg
W_m	Weight of matrix	kg
z_k	Distance of kth layer of laminate from mid-plane	mm

CHAPTER 1

INTRODUCTION

Structural crashworthiness becomes an essential requirement in the design of automobiles, rail cars and aerospace application. The structural crashworthiness covers the energy absorbing capability of collapsible and non-collapsible elements. The later is designed to provide a protective shell around the occupants i.e. post crash structural integrity.

Traditionally, fuselages of fixed-wing transport aircrafts are made mostly of aluminium [1], a material with a considerable capacity for plastic deformation, hence, an inherent capability to absorb energy in crash situations. Since the last two decades, composite materials are used more extensively to build aircraft structures. However, the crashworthiness aspect related to composite structures has become a serious issue for many space organizations worldwide. For example, NASA Langley Research Center developed an innovative and cost-effective crashworthy fuselage concept for light aircraft and rotorcraft [1, 11].

1.1 Composite Keel Beam

As stated earlier, the primary design goal for crashworthiness is to limit the impact forces transmitted to the occupants. To meet this objective, aircraft or rotorcraft sub-floor elements must be designed for high-energy absorption to prevent structural collapse during a crash [10]. Yet, the sub-floor design must not be so stiff that transmits or amplifies high impact loads to the occupants. Ideally, the design should contain some crushable elements to control limit the loads transmitted to the occupant to survivable or non-injurious levels [2, 10 and 12]. In this case, many investigations have been carried out on sub-floor using crushable elements [4, 5, 13, 14, 15, 16 and 17]. A lightweight energy-absorbing keel beam concept was developed and retrofitted in a general aviation-type aircraft and helicopter to improve crashworthiness performance [4, 13]. For example, more recently in the year 2004 Airbus achieved a world premiere with the A340-600 model, which features the longest carbon fibre keel beam ever built for a civil airliner [18].

1.2 Research Objectives

The primary objective of this current project is to develop a new composite keel beam to be used as main crush element in the aircraft sub floor. Accordingly the detailed objectives are:

1. To design and fabricate everting elements to control composite keel beam