UNIVERSITI PUTRA MALAYSIA

CRASH SIMULATION OF A COMPOSITE UNMANNED AERIAL VEHICLE FUSELAGE

NOORFAIZAL BIN DATO' HJ. YIDRIS

CRASH SIMULATION OF A COMPOSITE UNMANNED AERIAL VEHICLE FUSELAGE

By

NOORFAIZAL BIN DATO' HJ. YIDRIS

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

July 2007

CRASH SIMULATION OF A COMPOSITE UNMANNED AERIAL VEHICLE FUSELAGE

NOORFAIZAL BIN DATO' HJ. YIDRIS

MASTER OF SCIENCE

UNIVERSITI PUTRA MALAYSIA

2007

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

CRASH SIMULATION OF A COMPOSITE UNMANNED AERIAL VEHICLE FUSELAGE

By

NOORFAIZAL BIN DATO' HAJI YIDRIS

July 2007

Chairman: **Ahmad Samsuri Mokhtar, PhD**

Faculty: **Engineering**

In this research the results of experimental works and numerical simulation works pertaining to the crash behavior and crashworthiness characteristic of the upper part of the composite unmanned aerial vehicle (UAV) fuselage sections that were subjected to quasi-static transverse compressive loading are presented in detail. The influence of varying angles of lamina and special cases of laminates is thoroughly analyzed. The fuselage sections were made of 8 plies of C-glass/epoxy in a $[45/-45/90/0]_s$ layup. Two types of density of C-glass/epoxy, 200 g/m^2 and 600 g/m^2, were used with a total thickness of 0.00224 m and 0.004 m respectively for the 8-plies. Each ply has a thickness of 0.00028 m for C-glass/epoxy 200 g/m^2 and 0.0005 m for C-glass/epoxy 600 g/m^2. The C-glass/epoxy fuselage section was compressed using MTS machine of 250 kN loading capacity at very low-strain rate typical for static testing. The experimental data are correlated with predictions from a finite

element model developed using the ABAQUS/Standard with user subroutine. The simulation of the composite fuselage sections was carried out, refined several times and validated with the experimental results. The ABAQUS analysis results for both the C-glass/epoxy 200 g/m^2 and C-glass/epoxy 600 g/m^2 fuselage sections agreed well with the experimental data. ABAQUS analyses predicted the location of progressive damage to the sections using three failure theories, Maximum Stress Failure Theory, Tsai-Hill Failure Theory and Tsai-Wu Failure Theory. Tsai-Hill Failure Theory is found to have the least error percentage compared to the other two failure theories used. Finally, the finite element model was then used to study the influence of varying angles of lamina and special cases of laminates. 15^o angle of lamina and cross-ply laminate is found to have the most energy absorption.

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

SIMULASI HENTAMAN BADAN PESAWAT TANPA PEMANDU BERKOMPOSIT

Oleh

NOORFAIZAL BIN DATO' HAJI YIDRIS

Julai 2007

Pengerusi: **Ahmad Samsuri Mokhtar, PhD**

Fakulti: **Kejuruteraan**

Hasil-hasil penemuan dari kerja-kerja ujikaji dan simulasi berangka berkenaan dengan kelakuan hempasan dan sifat-sifat kebolehtahanan-hempasan bagi bahagian atas seksyen badan pesawat tanpa pemandu akibat daya mampatan disampaikan dengan terperinci. Pengaruh sudut lamina yang berbeza dan kumpulan lamina yang tertentu dianalisis dengan teliti. Seksyen badan pesawat dibuat daripada 8 lapisan C-glass/epoxy mengikut sudut lapisan $[45/-45/90/0]_S$. Dua jenis ketumpatan digunakan iaitu 200 g/m^2 and 600 g/m^2 dan masing-masing mempunyai ketebalan keseluruhan bagi 8 lapisan, 0.00224 m dan 0.004 m. Setiap lapisan berketebalan 0.00028 m untuk C-glass/epoxy 200 g/m^2 dan 0.0005 m untuk C-glass/epoxy 600 g/m^2. Seksyen badan pesawat dikenakan daya mampatan pada kadar terikan yang perlahan tipikal untuk ujikaji statik menggunakan mesin MTS berkeupayaan 250 kN. Data-data ujikaji dihubungkaitkan dengan data-data jangkaan dari model unsur terhingga yang

dibangunkan menggunakan program ABAQUS/Standard. Simulasi seksyen badan pesawat berkomposit dijalankan, diperhalusi beberapa kali dan disahkan dengan data-data ujikaji. Data-data analisis program ABAQUS bagi kedua-dua jenis ketumpatan badan pesawat serupa dengan data-data ujikaji. Analisa program ABAQUS berjaya meramalkan kedudukan kerosakan-kerosakan ke atas seksyen badan pesawat menggunakan tiga teori kegagalan, Teori Kegagalan Tegasan Maksimum, Teori Kegagalan Tsai-Hill dan Teori Kegagalan Tsai-Wu. Teori Kegagalan Tsai-Hill didapati mendapat peratus kesilapan yang paling rendah berbanding dengan dua teori kegagalan yang lain. Model unsur terhingga tersebut digunakan untuk mengkaji pengaruh sudut lamina yang berbeza dan kumpulan lamina yang tertentu. Sudut lamina 15^{o} dan lapisan lamina bersilang didapati mempunyai tenaga penyerapan hempasan yang tinggi.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to Dr. Elsadig Mahdi Ahmed Saad for his encouragement, valuable advice, and guidance through my years as a master student. It is a pleasure and an honour to be his student.

I would like also to express my sincere gratitude and deep thanks to my committee member, Dr. Ahmad Samsuri Mokhtar for his kind assistance, advice, encouragement, and suggestions throughout this work and during the preparation of this thesis. I would like to thanks to Dr. Rizal Zahari, En. Ropie Mat and all who have helped in the process of this work.

I certify that an Examination Committee met on July 16, 2007 to conduct the final examination of Noorfaizal Bin Dato' Hj. Yidris on his master of science thesis entitled "Crash Simulation of a Composite Unmanned Aerial Vehicle Fuselage" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Mohd Ramly Bin Ajir, MSc
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abd. Rahim Abu Talib, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal examiner)

Faizal Mustapha, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ahmad Kamal Ariffin Mohd Ihsan, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(External Examiner)

____

HASANAH MOHD GHAZALI, PhD

Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

Ahmad Samsuri Mokhtar, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Rizal Zahari, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Elsadig Mahdi Ahmed, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____

AINI IDERIS, PhD

Professor/ Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NOORFAIZAL BIN DATO' HAJI YIDRIS

Date: 20 AUGUST 2007

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

[A]	Extensional compliance matrix
[B]	Coupling compliance matrix
[D]	Bending compliance matrix
M	Mass (kg)
g	Gravity acceleration ($m.s^{-2}$)
h	Height between the mass M and top of fuselage section (m)
v	Velocity of the mass M ($m.s^{-1}$)
Δ_{max}	Maximum displacement after deformation (m)
Mgh	Potential energy (J)
$Mv^2/2$	Kinetic energy (J)
P_{max}	Peak load (N)
E_{abs}	Absorbed crash energy (J)
E_s	Specific absorbed energy ($J.kg^{-1}$)
P_{avg}	Average crushing load (N)
CFE	Crush load efficiency
SE	Stroke efficiency of use ratio
D	Mean diameter (m)
L	Axial length (m)
t	Wall thickness (m)
E_{11}	Young’s modulus in longitudinal direction (Pa)
E_{22}	Young’s modulus in transverse direction (Pa)
G_{12}	In-plane shear modulus (Pa)
v_{12}	In-plane Poisson’s ratio

S_{11}	Tensile strength in longitudinal direction (Pa)
S_{22}	Tensile strength in transverse direction (Pa)
S_{12}	In-plane shear strength (Pa)
M_{max}	Maximum bending moment (N.m)
V_{max}	Maximum Shear ($N.m^{-2}$)
$S_{req'd}$	Required section modulus (m^3)
σ_{allow}	Allowable stress ($N.m^{-2}$)
I	Moment of Inertia (m^4)
c	Radius of the beam section (m)
τ_{avg}	Average shear stress (Pa)
A	Area (m^2)
R_A, R_B	Reaction forces (N)
W	Width (m)
ε_x, ε_y	Axial strain ($m.m^{-1}$)
γ_{12}	Shear strain (rad)
τ_{12}	Shear stress (Pa)
σ_x	Axial stress (Pa)

TABLE OF CONTENTS **Page**

CHAPTER 1

INTRODUCTION

This chapter describes the research background, problem statement, objectives, scopes of work of the research and the importance of the study to the engineering community in general and to unmanned aerial vehicle (UAV) researchers in particular.

1.1 Research Background

An unmanned aerial vehicle (UAV), which behaves same as an aircraft uses aerodynamic forces to provide lift. It does not carry a human to operate the vehicle but can be flied by an onboard computer and/or be piloted remotely. Some 48 countries currently own, some are planning, some are producing and some are acquiring UAV from foreign sources. In the U.S. alone, over 80 companies, universities, and government organizations are actively developing one or more of some 200 UAV designs. The U.S. military currently is operating some 2200 large and small UAV of over 20 types. Worldwide, there are an estimated 5000 UAV in use. Japan leads in commercial unmanned aircraft (UA) use, with some 2000 unmanned helicopters and 10,000 licensed operators working in the agricultural industry (Wong, 2001).

The advantages of having UAVs are many when compared to their manned counterparts. It is increasingly accepted that UAVs can fly over dangerous area and cost less to build and to operate. Pilot proficiency flying is eliminated or maintained on cheap semi-scale UAVs.

In general the purpose of an unmanned aerial vehicle is to carry out various operations for which the UAV is designed to accomplish such as scientific reconnaissance role, mapping, military survey, carrying weapons and lunching weapons, surveillance of borders and coasts, fire detection, search and rescue, etc. UAVs can generally be categorized as tactical, endurance, vertical takeoff and landing (VTOL), man portable, or hand-launched, optionally piloted vehicles (OPVs), micro air vehicles (MAVs), and research (the UAV equivalent of X-planes). (Rodrigo, 1999)

An article in Aviation Week & Space Technology in Jun 1998 reported that the range in price for UAVs is from $1000 to $26 million and the manned aircraft range in price from $20,000 to $500 million. Examples: The latest production version of the Air Force/Teledyne Ryan RQ-4/Global Hawk costs over $26 million, not including its payload, the Air Force/General Atomics RQ-1/Predator $3.3 million with payload, and the Navy/PUI RQ-2/Pioneer just over $900,000 with payload. Tactical size UAVs are commercially available in the $250,000 range with payload, the Aerosonde Robotic Aircraft's Atlantic-crossing Aerosonde runs $35,000, and MLB offers mini (not micro) UAVs for around $1000 per aircraft. The price of an UAV system can go up to two or ten times the price of its individual aircraft. The price of the UAV system includes its ground control station and shelter, launching