UNIVERSITI PUTRA MALAYSIA

# FLUTTER ANALYSIS OF A SCALED MODEL OF AN EAGLE 150B/AC WING

AZMIN SHAKRINE BIN MOHD RAFIE

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**By**

**AZMIN SHAKRINE BIN MOHD RAFIE**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**September 2007**

# DEDICATION

Alhamdulillah thanks to Allah the Almighty for the blessings and opportunities that He has provided the strength for me to accomplish this PhD study. This thesis is especially dedicated to;

My father and mother:
Mohd Rafie Hussain and Mariatul Kibtiah Mohd Yatim, thank you for your support, understanding and blessing to carry out this study.

My beloved wife:
Norazlinda Mohd Darby who constantly source of inspiration, motivation, encouragement and support throughout this study.

My son:
Muhammad Zunnurain, source of my inspiration.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**Chairman: Professor Ir. ShahNor Basri, PhD**

**Faculty: Engineering**

An investigation of the problem of the flutter condition of an Eagle 150B aircraft wing is undertaken. The research is largely devoted to investigating the adequacy of the ideal flutter theory that has been employed to predict flutter boundary for such wing. A series of panel flutter experiment carried out in UPM 1m × 1m wind tunnel at Mach number up to 0.132 are described in detail. Furthermore, an extensive parametric computational analysis has been conducted to improve flutter condition by reconfiguring the wing design specification. For experimental analysis, the ground test which includes static and dynamic tests of the wind model has been performed followed by the wind tunnel testing. The data gathered from the wind tunnel testing is analyzed using the logarithmic decrement method so that the flutter speed can be predicted. The wing model mounting system test rig has been designed and developed together with the data acquisition system which is used for data collection. In order to validate the experimental technique, wind tunnel testing using three different types of materials for rectangular flat plate has been conducted. The types of materials used are aluminum 6061, mild steel and stainless steel. The agreement between experimental technique and computational analysis is acceptable since the error of difference is less than 6 percent.

MSC. Patran and Nastran software have been used to predict the flutter condition since it has the capability to carry out the aeroelasticity analysis of the actual wing and wing model. The PK-method and aerodynamic doublet lattice methods were selected for this analysis as it provides the eigenvalue solutions in the form of the V-g and V-f graphs. Validation of the computational analysis with two existing published results is performed to ensure the results are reliable. The parametric study produced the results on the effects of the mass, altitude, span length, stiffness and center of gravity position against the flutter speed condition. This research work may conclude that both techniques are reliable to investigate flutter speed since the validation results showed a good agreement. It was also found that through extensive parametric study, several suggestions have been made to reconfigure the wing in order to improve the flutter condition.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**ANALISIS FLUTER UNTUK MODEL BERSKALA BAGI SAYAP PESAWAT EAGLE 150B**

Oleh

**AZMIN SHAKRINE BIN MOHD RAFIE**

**September 2007**

**Pengerusi:** **Profesor Ir. ShahNor Basri, PhD**

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Penyiasatan bagi masalah keadaan fluter untuk sayap pesawat Eagle 150B telah dilaksanakan. Penyelidikan ini menumpukan sepenuhnya untuk menyiasat kecekapan teori unggul fluter yang telah digunakan untuk meramal sempadan fluter sayap tersebut. Beberapa siri eksperimen panel fluter yang dijalankan di terowong angin 1m × 1m UPM pada nombor Mach sehingga 0.132 telah dinyatakan dengan teperinci. Selanjutnya, kajian parameter yang mendalam menggunakan kaedah analisis berkomputer telah dilakukan untuk memperbaiki lagi keadaan fluter dengan mengubah spesifikasi rekabentuk sayap. Untuk analisis eksperimen, ujian di dataran yang mengandungi ujian statik dan dinamik untuk model sayap telah dilaksanakan diikuti oleh ujian terowong angin. Data yang diperolehi daripada ujian terowong angin akan dianalisa mengunakan kaedah pengurangan logaritma di mana kelajuan fluter akan dapat diramal. Sistem rig ujian pencagak model sayap telah direkabentuk dan dibangunkan bersama dengan sistem perolehan data yang digunakan untuk mengumpul data. Untuk tujuan pengesahan analisis eksperimen, ujian terowong angin dengan menggunakan tiga jenis bahan yang berbeza untuk plat rata segi empat tepat telah dilakukan. Jenis bahan yang digunakan adalah aluminium 6061, besi

lembut dan keluli tahan karat. Kesesuaian antara teknik eksperimen dan analisis berkomputer adalah diterima memandangkan perbezaan ralat adalah kurang daripada 6 peratus.

Perisian MSC. Patran dan Nastran telah digunakan untuk meramal keadaan fluter di mana ia mempunyai kebolehan untuk menjalankan analisis keanjalan udara untuk analisis sayap sebenar dan sayap model. Kaedah PK dan kaedah aerodinamik gandaan kekisi telah dipilih untuk analisis ini di mana ia memberikan penyelesaian nilai eigen di dalam bentuk graf V-g dan V-f. Pengesahan analisis berkomputer dengan dua keputusan penerbitan yang sedia ada telah dilakukan untuk memastikan keputusan yang boleh dipercayai. Kajian parameter memberikan hasil kesan jisim, ketinggian, panjang sayap, keanjalan dan kedudukan pusat gravity terhadap keadaan kelajuan fluter. Kerja penyelidikan ini dapat menyimpulkan bahawa kedua teknik berkebolehan untuk menyiasat keadaan fluter disebabkan keputusan pengesahan menunjukan kesesuaian yang baik. Melalui kajian parameter yang mendalam, beberapa cadangan juga dapat dirumuskan untuk mengubah sayap pesawat dengan tujuan untuk memperbaiki lagi keadaan fluter.

## ACKNOWLEDEMENTS

First and foremost, Alhamdulillah thanks to Allah the Almighty for the blessings and opportunities that He has provided the strength for me to accomplish this PhD study. I would like to express my sincere gratitude to my advisor, Professor Dr. Ir. ShahNor Basri, who constantly source out good advice, encouragement and all kind of support throughout this study. He has consistently put the interest of his students first and always kept an open door policy. I am deeply indebted and most graceful to Dr.-Ing. Ir. Renuganth Varatharajoo and Dr. Ir. Prasetyo Edi, the supervisory committee members, who have guided this work and for their helpfulness discussion and advice. I'm highly appreciated for their time and willingness to serve as my supervisory committee.

I wish to extend my thanks to the staff of the Department of Aerospace Engineering for their friendly dealing and moral support. I'm gratefully acknowledged the help and patience of Mr. Ropiee Mat and Mr. Ahmad Saiful Abu Samah, the technicians of the Aerodynamic Lab and Structure Lab. I also thank my friends and colleagues especially tutor form Aerospace Department for sharing their knowledge and encouragement. Thanks must also go to my family members, my wife and son for their patience, understanding and encouragement as well as the wonderful environment they provided for the successful completion of this work. And lastly, I gratefully acknowledge the support of the Composites Technology Research Malaysia (CTRM) for the information and data of Eagle 150B aircraft wing and allow me to study this type of aircraft.

## APPROVAL

I certify that an Examination Committee met on 14 September, 2007 to conduct the final examination of Azmin Shakrine Bin Mohd Rafie on his degree of Doctor of Philosophy thesis entitled "Flutter Analysis of A Scaled Model of an Eagle 150B/AC Wing" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follws:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.

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Date: 15 November 2007

## 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 degree at UPM or other institutions.

**AZMIN SHAKRINE BIN MOHD RAFIE**

Date: 28 April 2008

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| | |
|---|---|
| AGARD | Advisory Group for Aerospace Research and Development |
| AR | Aspect Ratio |
| ARES | Aeroelasticity Rotor Experimental System |
| ASTM | Standard Test Method |
| CAE | Computational Aeroelasticity |
| CAP-TSD | Computational Aeroelasticity Program – Transonic Small Disturbance |
| CFD | Computational Fluid Dynamic |
| CG | Center of Gravity |
| CSM | Computational Structural Mechanics |
| CTRM | Composites Technology Research Malaysia |
| DAQ | Data Acquisition |
| DLM | Doublet-Lattice Method |
| EA | Elastic Axis |
| EE | Euler equations |
| FE | Finite Element |
| FFT | Fast Fourier Transformation |
| FP | Full Potential |
| Hz | Hertz |
| ICW | Intermediate Complexity Wing |
| LCO | Limit Cycle Oscillation |
| LE | Leading Edge |
| MSC Nastran | MacNeal-Schwendler Corporation – NASA Structural Analysis |

| | |
|---|---|
| NASA | National Aeronautics and Space Administration |
| PAPA | Pitch and Plunge Apparatus |
| RAE | Royal Aeronautical Establishment |
| RBAR | Rigid Bar |
| RPM | Rotations per Minute |
| SDOF | Single Degree of Freedom |
| TDT | Transonic Dynamics Tunnel |
| TE | Trailing Edge |
| TLNS | Thin Layer Navier-Stokes Equations |
| TSD | Transonic Small Disturbance |
| TWG | Transonic Wind Tunnel Gottingen |
| VS | Virtual Surface |

**Nomenclature**

| | |
|---|---|
| $[A(t)]$ | Matrix of unsteady aerodynamics operators |
| $A$ | Constant |
| $c$ | Chord |
| $C$ | Cos (θ) |
| $C(k)$ | Theodorsen's function |
| $C_p$ | Pressure data |
| $[D]$ | Damping matrix |
| $e$ | Exponential |
| $E$ | Modulus of elasticity |
| $E_1$ | Longitudinal Young's modulus |
| $E_2$ | Transverse Young's modulus |

| | |
|---|---|
| $EI$ | Bending stiffness |
| $f_f$ | Flutter frequency |
| $g$ | Damping factor |
| $G$ | Shear modulus of elasticity |
| $G_{12}$ | In-plane shear modulus |
| $GJ$ | Torsional stiffness |
| $H_n^{(2)}(k)$ | Hankel functions of the second kind |
| $h,\ \alpha$ | Deflection in bending and torsional directions |
| $\bar{i}, \bar{k}$ | A unit of Cartesian vector |
| $i$ | imaginary number |
| $I$ | Moment of inertia |
| $I_\alpha$ | Mass moment of inertia |
| $J$ | Polar moment of inertia |
| $[K]$ | Stiffness matrix |
| $k_t$ | Constant thickness for each layers |
| $k$ | Reduced frequency |
| $K$ | Kernel function |
| $K_\alpha$ | Torsional stiffness |
| $K_h$ | Bending stiffness |
| $l, L$ | Span length |
| $L$ | Vertical force per unit span |
| $[M]$ | Mass matrix |
| $m$ | Mass per unit length |
| $M_\infty$ | Mach number |
| $M_y$ | Moment force about y axis per unit span |

| | |
|---|---|
| $N_{lay}$ | Total number of layers |
| $P_t$ | Load at tip |
| $P$ | Pressure |
| $P_\infty$ | Pressure at free stream |
| $\{q\}$ | Vector of generalized coordinates |
| $\overline{Q}$ | Transformed reduced stiffness coefficients |
| $q$ | Dynamic pressure |
| $Q$ | Reduced stiffness coefficients |
| $q_1, q_2$ | Generalized coordinate |
| $Q_h, Q_\alpha$ | Generalized forces |
| $q_i$ | ith generalized coordinate |
| $R$ | Gas constant for air |
| $\vec{r}$ | Displacement of any point |
| $r$ | Radius of gyration |
| $S$ | Sin (θ) |
| $S_\alpha$ | Static moment |
| $T^\circ$ | Atmospheric temperature |
| $T$ | Kinetic energy |
| $t$ | Time |
| $T_t$ | Torsional force at tip |
| $T_d$ | Damped period |
| $u$ | Horizontal displacement |
| $U$ | Potential energy |
| $V, V_\infty$ | Free stream velocity |
| $V_b$ | Vertical velocity vector due to bending |

| | |
|---|---|
| $V_f$ | Flutter speed |
| $V_r$ | Resulting velocity vector at wing |
| $w$ | Vertical displacement |
| $w_a$ | Vertical velocity component over airfoil contour |
| $x$ | Deflection in x direction |
| $X_1, X_2$ | Amplitudes |
| $X_{cg}$ | Distance from center of gravity |
| $\{Z\}$ | Force vector |
| $Z$ | Distance from center line |
| $z_a$ | Vertical displacement of airfoil at point x, z and t |

**Greek Symbols**

| | |
|---|---|
| $\alpha$ | Geometric angle of attack |
| $\varepsilon_1$ | Longitudinal tensile strain |
| $\sigma_2$ | Transverse tensile stress |
| $\alpha_{eff}$ | Effective angle of attack of wing |
| $\alpha_{ind}$ | Induced angle of attack due to bending |
| $\varnothing_t$ | Angle deflection at tip |
| $\gamma_a, \gamma_w$ | Circulation along airfoil and wake |
| $\delta$ | Logarithmic decrement |
| $\delta_t$ | Deflection at tip |
| $\varepsilon_2$ | Transverse tensile strain |
| $\zeta$ | Damping ratio |
| $\theta$ | Angle of lamina |
| $\mu$ | Mass ratio |