UNIVERSITI PUTRA MALAYSIA

SUBSONIC AEROELASTIC ANALYSIS OF A THIN FLAT PLATE

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ITMA 2001 6

SUBSONIC AEROELASTIC ANALYSIS OF A THIN FLAT PLATE

By

DAYANG LAILA BT. ABANG HAJI ABDUL MAJID

Thesis Submitted in Fulfilment of the Requirement for the Degree of
Master of Science in the Institute of Advanced Technology
Universiti Putra Malaysia

March 2001

DEDICATION

Alhamdulillah, thanks to Allah s.w.t. upon the completion of this thesis. This thesis is specially dedicated to my beloved father, Abang Haji Abdul Majid bin Abang Taha, who during his lifetime, had continuously stressed on his children to strive for a better education. I only hope that I have inherited his great wisdom to pass on to my own children.

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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The interaction between an aircraft structure and the airflow surrounding it has been known to severely affect the stability, performance and manoeuvrability of the aircraft. These interactions form the heart of aeroelasticity, a field that comprises all types of aeroelastic phenomena. In this work, a parametric aeroelastic analysis of a thin flat plate clamped at the leading edge and exposed to subsonic airflow was conducted. The aeroelastic effects predicted to occur was flutter, a type of self-excited oscillation.

The analysis was simulated using ZAERO, a panel code aeroelastic program, which requires free vibration input, obtained using MSC-NASTRAN, a finite element code. The flutter equation was obtained using Newton's Law of Motion to model the plate while the airflow was modeled using the Small Disturbance Unsteady Aerodynamic Theory. Free vibration results and flutter results obtained were validated against published works found in reference [8, 60 and 61].

The important parameters studied were the aspect ratio and the mass ratio of the plate. The effect of the number of free vibration modes employed in the analysis was also tested. From the results, it was shown that the flutter velocity decreased as the mass ratio and aspect ratio were increased. The flutter frequency also decreased with higher mass ratio and at large aspect ratio. The use of a higher number of modes in the flutter analysis was found to increase the accuracy of the flutter.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains.

ANALISIS AEROELASTIK SUBSONIK UNTUK SEBUAH PLAT YANG NIPIS DAN RATA

Oleh

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Interaksi antara struktur pesawat dan udara sekelilingnya telah diketahui boleh mempengaruhi kestabilan, prestasi dan olahgerak pesawat tersebut. Interaksi inilah yang merupakan nadi keaeroelastikan, suatu bidang yang merangkumi kesemua jenis fenomena aeroelastik. Dalam kerja ini, analisis parametrik aeroelastik untuk suatu plat nipis dan rata yang diikat pada hujung mendahulu dan terdedah kepada aliran subsonik telah dijalankan. Kesan aeroelastik yang dijangka berlaku adalah 'flutter', iaitu sejenis getaran teruja sendiri.

Simulasi ini telah dijalankan menggunakan ZAERO, perisian aeroelastik berasaskan kod panel, yang memerlukan input getaran bebas diperolehi menggunakan MSC-NASTRAN, sebuah kod elemen terhingga. Persamaan untuk 'flutter' diperolehi dengan menggunakan teori Gerakan Newton untuk model plat dan aliran udara dimodel dengan menggunakan teori Aerodinamik Gangguan Kecil dan Tak Mantap. Keputusan getaran bebas dan 'flutter' diperolehi dan disahkan oleh hasil-hasil kerja yang telah diterbitkan dalam rujukan [8, 60 dan 61].

Parameter-parameter penting yang dikaji adalah nisbah aspek dan nisbah jisim plat tersebut. Kesan daripada bilangan mod getaran bebas yang digunakan dalam analisis juga dikaji. Daripada keputusan, didapati halaju 'flutter' berkurang apabila nisbah aspek dan nisbah jisim bertambah. Frekuensi 'flutter' juga didapati menurun dengan pertambahan nisbah aspek dan nisbah jisim. Penggunaan bilangan mod yang tinggi dalam analisis 'flutter' didapati telah memperbaiki ketepatan 'flutter'.

ACKNOWLEDGEMENTS

Alhamdulillah, thanks to Allah s.w.t. for the completion of this thesis. I would like to acknowledge the complete support and advice given by Associate Prof. ShahNor Basri, my thesis supervisor, throughout the course of my master degree. In spite of all the 'headaches' I put him through, he has consistently put the interest of his students first and always kept an open door policy.

I am also grateful to Dr. Waqar, Faizal, Aznijar and the rest of the staff in Aerospace Engineering for their continuous support and kind words. To my wonderful friends, Kak Ina, Kak Rin, Ila and Kak Milah, thank you for your help and valuable advice. One of the best things of doing this work was in acquiring friends like you that do not hesitate to provide shoulders for me to cry on when the going gets too tough.

And lastly, to my wonderful family, your unfailing support and love have encouraged me at every turn. I will always cherish their constant encouragement during my study and in my life.

TABLE OF CONTENTS

Page

DEDICATION ii
ABSTRACT iii
ABSTRAK v
ACKNOWLEDGEMENTS vii
APPROVAL SHEETS viii
DECLARATION FORM x
LIST OF TABLES xiv
LIST OF FIGURES xv
LIST OF ABBREVIATIONS xix

CHAPTER

1. INTRODUCTION 1

  1.1 Introduction 1
  1.2 Panel Flutter 3
  1.3 Scope and Objective of Research 5

2. REVIEW OF PREVIOUS WORK 6

  2.1 Engineering Background 6
  2.2 Experimental Aeroelasticity 8
  2.3 Computational Aeroelasticity 10
    2.3.1 Static Aeroelasticity 11
    2.3.2 Dynamic Aeroelasticity 15
  2.4 Closure 25

3. THEORY 27

  3.1 Governing Equation of Motion 27
  3.2 Aerodynamic Equation 30
    3.2.1 Model of the Fluid Element 31
    3.2.2 Integral Solutions to Linearised Small Disturbance Equation 34
    3.2.3 Unsteady Boundary Condition and Pressure Coefficients 37
  3.3 Flutter Equation of Motion 40
  3.4 Closure 42

4. MODELLING & NUMERICAL METHOD 43

  4.1 Solution Technique 43
    4.1.1 MSC-NASTRAN's Finite Element Method 43
    4.1.2 ZAERO'S Panel Method 45

4.1.3 Data Transformation Between Finite Element Model and Panel Model 46
4.2 Solution Algorithm 48
4.3 Closure 53

5. NUMERICAL VALIDATION 61

5.1 Validation of Natural Frequencies 61
5.2 Validation of Flutter 65
5.3 Closure 68

6. RESULTS AND DISCUSSION 71

6.1 General Understanding of ZAERO Results 71
6.2 Comparison of g- and K-Method 74
6.3 Flutter Accuracy 77
6.4 Flutter Comparison of Different Materials 80
6.5 Parametric Studies 82
6.5.1 Effects of Small Aspect Ratio 83
6.5.2 Effects of Large Aspect Ratio 85
6.5.3 Effects of Mass Ratio 86
6.5.4 Unsteady Pressure Distribution 88
6.5.5 Structural Mode Shapes 89
6.5.6 Flutter Mode Shapes 90
6.6 Closure 91

7. CONCLUSION AND RECOMMENDATION FOR FUTURE WORK 126

7.1 Validation of Codes 126
7.2 Computed Results 127
7.3 Theoretical Aspects 129
7.4 Recommendation for Future Work 130

REFERENCES 131

APPENDICES

Appendix A1 Derivation of the Continuity Equation 136
Appendix A2 Derivation of the Momentum Equation 137
Appendix A3 Derivation of the Unsteady Bernoulli Equation 138
Appendix A4 Derivation of Linearised Small-Disturbance Velocity Potential Equation 140
Appendix A5 Derivation of the Flutter Equation 142
Appendix B1 Finite Element Formulation 144
Appendix B2 An Example of MSC-NASTRAN's Output File 145
Appendix B3 Description of ZAERO's Input File 168

Appendix B4 ZAERO's Engineering Application Modules 169
Appendix B5 An Example of Zaero's Flutter Results Using The g-Method and K-Method 170
Appendix C1 Analytical Calculation of First and Second Natural Frequency For A Flat Plate 184

VITA 186

LIST OF TABLES

Table		Page
5.1	Material Properties of Aluminum Plate	69
5.2	Arrangement of Nodes in the x- and y-direction	70
5.3	Comparison of Natural Frequencies	71
5.4	Comparison of Flutter Frequency and Velocity	73
6.1	Flutter Velocity and Frequency at a) AR = 1; b) AR = 5; c) AR = 10; and d) AR = 20	86
6.2	Material Properties of Aluminum	88
6.3	Natural Frequencies for Different Types of Aluminum	88

LIST OF FIGURES

Figure		Page
1.1	Aeroelastic Problem Tree	2
2.1(a)	Clamped-clamped,	23
2.1(b)	Clamped-free Panel Configuration	23
3.1	Schematic of the Rectangular Plate Model	28
3.2	Aeroelastic Feedback Diagram	29
3.3	Finite Control Volume Fixed in Space	31
3.4	Surface Definition of Plate and Wake	37
4.1(a)	Plate Meshed into Nodes and Elements	54
4.1(b)	Plate with Boundary Conditions	54
4.2	Meshed Aerodynamic Model with Flow Over Top and Bottom of A Plate	55
4.3(a)	Outer Loop of the Lanczos Method	56
4.3(b)	Inner Loop of the Lanczos Method	57
4.4	ZAERO Main Program Flow Chart	58
4.5	g-method Flutter Solution Flow Chart	59
4.6	K-method Flutter Solution Flow Chart	60
5.1	Comparison of Non-Dimensional Frequency with Published Results at a) AR=1; b)AR=1.5; and c) AR=2.5	69
5.2	Non-Dimensional Frequency versus Mass Ratio	70
5.3	Non-Dimensional Dynamic Pressure versus Mass Ratio	70
6.1	General Representation of Damping versus Freestream Velocity	93

6.2 General Representation of Frequency versus Freestream Velocity 94

6.3 Damping versus Freestream Velocity: Comparison of g- and K-Method 95

6.4 Frequency versus Freestream Velocity: Comparison of g- and K-Method 95

6.5 Flutter Frequency versus No.of Modes at a) AR=1; b) AR=5; c) AR=10; and d) AR=20 96

6.6 Flutter Frequency versus No. of Modes at a) AR=1; b) AR=5; c) AR=10; and d) AR=20 97

6.7 Damping versus Freestream Velocity: Comparison of Different Aluminums 98

6.8 Frequency versus Freestream Velocity: Comparison of Different Aluminums 98

6.9 Damping versus Freestream Velocity at Small Aspect Ratio 99

6.10 Frequency versus Freestream Velocity at Small Aspect Ratio 100

6.11 Flutter Velocity versus Small Aspect Ratio 101

6.12 Flutter Frequency versus Small Aspect Ratio 101

6.13 Damping versus Freestream Velocity at Large Aspect Ratio (AR > 4) 102

6.14 Frequency versus Freestream Velocity at Large Aspect Ratio (AR > 4) 103

6.15 Flutter Velocity versus Large Aspect Ratio (AR > 4) 104

6.16 Flutter Frequency versus Large Aspect Ratio (AR > 4) 104

6.17 Damping versus Freestream Velocity at Different Mass Ratio 105

6.18 Frequency versus Freestream Velocity at Different Mass Ratio 106

6.19 Flutter Velocity versus Mass Ratio at Different Aspect Ratio 107

6.20 Flutter Frequency versus Mass Ratio at Different Aspect Ratio 107

6.21 Unsteady Pressure Distribution at Various Reduced Frequencies for A Plate with AR = 1 108

6.22 Unsteady Pressure Distribution at Various Reduced Frequencies for A Plate with AR = 5 109

6.23 Unsteady Pressure Distribution at Various Reduced Frequencies for A Plate with AR = 20 110

6.24 Unsteady Pressure Distribution at Various Reduced Frequencies for A Plate with Mass Ratio = 0.1 111

6.25 Unsteady Pressure Distribution at Various Reduced Frequencies for A Plate with Mass Ratio = 0.3 112

6.26 Unsteady Pressure Distribution at Various Reduced Frequencies for A Plate with Mass Ratio = 0.5 113

6.27 Structural Mode Shapes from Mode 1 to 6 for A Plate with AR = 1 114

6.28 Structural Mode Shapes from Mode 1 to 6 for A Plate with AR = 5 115

6.29 Structural Mode Shapes from Mode 1 to 6 for A Plate with AR = 20 116

6.30 Structural Mode Shapes from Mode 1 to 6 for A Plate with Mass Ratio = 0.1 117

6.31 Structural Mode Shapes from Mode 1 to 6 for A Plate with Mass Ratio = 0.3 118

6.32 Structural Mode Shapes from Mode 1 to 6 for A Plate with Mass Ratio = 0.5 119

6.33 Flutter Mode Shapes at Different Time Interval for A Plate with AR = 1 120

6.34 Flutter Mode Shapes at Different Time Interval for A Plate with AR = 5 121

6.35 Flutter Mode Shapes at Different Time Interval for A Plate with AR = 20 122

6.36 Flutter Mode Shapes at Different Time Interval for A Plate with Mass 123

Ratio = 0.1

6.37 Flutter Mode Shapes at Different Time Interval for A Plate with Mass Ratio = 0.3 124

6.38 Flutter Mode Shapes at Different Time Interval for A Plate with Mass Ratio = 0.5 125

LIST OF ABBREVIATIONS

a_∞	speed of sound
b	width of plate
g	aerodynamic damping
g_s	structural damping
h_x, h_y, h_z	interpolated deformation at aerodynamic boxes in x,y,z direction
h_m	plate's thickness
k	reduced frequency
l	length of plate
m	mass
$\vec{n}$	unit surface normal
$n_x,\ n_y,\ n_z$	components of $\vec{n}$ in the x, y and z direction
p	pressure
p_1	dummy integration variable
p_{ref}	reference pressure
q_∞	freestream dynamic pressure
q	Lanczos vector
t	time
$u,\ v,\ w$	velocity component in the x, y and z direction
$\hat{u}, \hat{v}, \hat{w}$	perturbation velocity in the x, y and z direction
$\hat{u}_o, \hat{v}_o, \hat{w}_o$	steady perturbation velocity in the x, y and z direction
x,y,z	global coordinates

∇	gradient operator
α,β	scalar coefficient of $[T]$ matrix
ε	elementary source solution
γ	specific heat ratio
ϕ	velocity potential
$\hat{\phi}$	perturbation velocity potential
$\overline{\phi}$	modified potential
ρ_a	air density
ρ_{a1}	dummy integration variable
ρ_m	mass density
σ	source singularity
Φ	doublet singularity
Ω	complex eigen-value
τ	compressible reduced frequency
ω	natural frequency
ω_f	flutter frequency
$\overline{\omega}$	non-dimensional frequency
λ	eigenvalue
μ	eigenvalue of $[T]$ matrix
ξ,η,ζ	local coordinates
$[\varphi]$	modal matrix
A	fluid element's surface

dA	surface elemental area
C_p	pressure coefficient
D	flexural rigidity
E	Young's modulus
$[\bar{C}]$	damping matrix
$\{F(t)\}$	total aerodynamic force
$\{F_a(\chi)\}$	aerodynamic force induced by structural deformation
$\{F_e(t)\}$	external aerodynamic force
$\{F_{b\}}$	downwash function on arbitrary bodies
$\{F_w\}$	downwash function on flat plate type of lifting surface
$[G]$	spline matrix
$\{h\}$	interpolated deformation at aerodynamic boxes
$[H^e]$	strain-displacement matrix
K_{sub}	Subsonic Kernel
K_{super}	Supersonic Kernel
$[K]$	generalized stiffness matrix
$[\bar{K}]$	stiffness matrix
L	reference length of plate, $b/2$
$[M]$	generalized mass matrix
$[\bar{M}]$	mass matrix
M_∞	freestream Mach number
$[N]$	shape function
$N_{x,,}$ N_y	number of nodes in x and y direction

R_x, R_y, R_z	rotational degree-of-freedom at x,y,z direction
$Q(ik)$	generalized aerodynamic force
$\{\bar{q}\}$	generalized coordinates
$\{\bar{z}\}$	eigen-vector of $[T]$ matrix
S	surface of plate
T_x, T_y, T_z	translational degree-of-freedom at x,y,z direction
$\vec{U}$	fluid velocity vector
U_f	flutter velocity
U_∞	freestream velocity
V	fluid element's volume
W	wake surface
$\bar{Z}$	modal structural damping
$\{\chi(t)\}$	displacement vector
$\{\ddot{\chi}(t)\}$	acceleration vector
$\{\hat{\chi}\}$	displacement amplitude vector
$[AIC]$	aerodynamic influence coefficient matrix
$\dfrac{\rho_a l}{\rho_m h_m}$	mass ratio

$$B = \sqrt{\left|1 - M_\infty{}^2\right|}$$

$$\tilde{A} = \left(\frac{U^2}{L^2}\right)M$$

$$\tilde{B} = 2ik\left(\frac{U}{L}\right)^2 M - \frac{1}{2}\rho U^2 Q'(ik) + \left(\frac{U}{L}\right)Z$$

$$\widetilde{\mathrm{C}} = -\mathrm{k}^2\left(\frac{\mathrm{U}}{\mathrm{L}}\right)^2 \mathrm{M} + \overline{\mathrm{K}} - \frac{1}{2}\rho \mathrm{U}^2 \mathrm{Q}(\mathrm{ik}) + \mathrm{ik}\left(\frac{\mathrm{U}}{\mathrm{L}}\right)\mathrm{Z}$$

where *Z* is a a modal structural damping matrix and $\mathrm{Q}'(\mathrm{ik}) = \dfrac{\partial \mathrm{Q}(\mathrm{ik})}{\partial(\mathrm{ik})}$.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Modern aircraft structures are extremely flexible and therefore tend to deform when exposed to airflow [1]. This usually involves the interaction of inertial, elastic and aerodynamic forces, which consequently may result in static and dynamic deformations and instabilities. Aeroelasticity deals with the behaviour of an elastic body or vehicle in an air stream, whereby there is significant reciprocal interaction or feedback between deformation and flow [2]. These aeroelastically-induced deformations may have severe consequences on the stability, performance and manoeuvrability of an aircraft. However, dynamic instabilities often provide more cause for concern than static instabilities, whereby the final consequence usually leads to failure.

Because of this practical consequence, understanding of the aeroelastic behaviour is critical, which necessitates the need for reliable prediction tools that can model all the important characteristics of the interaction. As an interdisciplinary field, aeroelasticity requires the coupling of the aerodynamic and structural responses. Computationally, this will involve coupling of computational disciplines such as Computational Fluid Dynamics (CFD) and Computational Structural Dynamics (CSD), which are generally referred to as Computational Aeroelasticity (CA) [3]. From an engineering viewpoint, the major aim in computational aeroelasticity is therefore to describe the influence of structural deformations on the aerodynamic load and vice versa.