STUDY OF FLUTTER ON A COMPOSITE UAV WING

NURUL ZUBAIDAH BINTI ZAKI

A thesis submitted in fulfilment of the
requirements for the awards of the degree of
Master of Science (Aeronautical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JANUARY 2017

To my parents Shariffah Hamidah Syed Sulaiman and Zaki Samat for their invaluable guidance and relentless support with the promise that I will never stop to follow my dreams

ACKNOWLEDGEMENT

In preparing this dissertation, I was in contact with many people around me, trying to approach them to discuss all the problems and they help me to find a solution for the problems that I have face. I am grateful to have such a nice friends, family and fellow staffs in UTM who helps me during the process of preparing this thesis.

I am also sincerely grateful towards my supervisor, Assoc. Prof. Ainullotfi bin Abdull Latif for giving me new knowledge of the things that I have not learn and experienced before.

I am also grateful to all of my family members especially my parents who are willing to support me mentally and always be right by my side during the hard time that I faced.

ABSTRACT

A study of flutter of the UAV composite wing has been done by considering the aeroelasticity phenomenon which involves the dynamic instability of a structure which able to lead a catastrophic failure. To prevent any failure, various design effects and materials parameters of the wing structure for a composite UAV wing are being considered in the study as it able to give a significant effect towards the flutter.The flutter velocity can be obtained by deriving the equation from the binary wing model which governs by mathematical equation related to the effect of aerodynamic damping and stiffness as well as structural damping and stiffness. The most important parameters in this study is the heaving stiffness, K_u and pitching stiffness, K_θ which is resulted from the derivation of the full aeroelastic equation of motion. The stiffness can be obtained by simulating or analysis of the wing structures in the finite element software, Abaqus/CAE 6.13-EF1 where the natural frequencies of the bending and torsional can be obtained. The equation of full aeroelastic motion can be solved by finding its eigenvalue from the MATLAB software by writing the script file. The flutter speed can be obtained from the intersection point of heaving and pitching frequency across the speed as well as at the point where the damping ratio is zero along the air speed. From the study, a sets of spar and ribs at certain location across the wing has been proves to produce a higher flutter velocity which is 162.31 $\mathrm{m/s}$.

ABSTRAK

Kajian tentang kibaran yang berlaku ke atas pesawat tanpa penumpang telah dijalankan dengan mengambil kira fenomena aeroelastisiti yang merangkumi ketidakstabilan dinamik terhadap struktur yang boleh membawa kepada kemalangan akibat dari kegagalan fungsi pesawat. Bagi mengelakkan sebarang kegagalan berlaku, pelbagai kesan reka bentuk dan parameter material struktur wing yang diperbuat dari komposit telah diambil kira didalam kajian ini. Kelajuan kibaran boleh didapati daripada persamaan penuh aeroelastik yang mengambil kira kesan daripada redaman dan ketegangan aerodinamik serta redaman dan ketegangan struktur. Antara parameter yang memainkan peranan penting di dalam persamaan penuh aeroelastik ialah ketegangan lenturan, K_u dan ketegangan kilasan, K_θ. Kedua-dua ketegangan ini boleh diperolehi daripada analisis atau simulasi sayap pesawat di dalam perisian unsur terhingga, Abaqus/CAE 6.13-EF1 di mana kekerapan semulajadi lenturan dan kilasan boleh diperolehi. Persamaan penuh aeroelastik boleh diselesaikan dengan mencari nilai eigen dengan menggunakan perisian MATLAB yang merangkumi skrip file. Kelajuan kibaran kemudiannya boleh diperolehi dari titik persilangan antara kekerapan lenturan dan kekerapan kilasan terhadap kelajuan angin serta menggunakan titik di mana nisbah redaman adalah sifar. Berdasarkan kajian yang telah dijalankan, sebuah set struktur dalaman sayap pesawat telah dibuktikan mampu untuk menghasilkan kelajuan kibarang paling tinggi iaitu 162.31 $\mathrm{m/s}$.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

V - Velocity
b - Wing semi-chord
e - Eccentricity between flexural axis and aerodynamic centre
L - Lift per unit span
L_z - Heaving displacement due to lift
$L_{\dot{z}}$ - Heaving velocity due to lift
L_θ - Pitching displacement due to lift
$L_{\dot{\theta}}$ - Pitching velocity due to lift
ρ - Air density
$\Phi(\tau)$ - Wagner’s function
k - Reduced frequency
c - Wing chord
v - Frequency parameter
H_n^2 - Hankell’s function of second kind
C_M - Wing moment coefficient
M - Moment per unit span
M_z - Heaving displacement due to moment
$M_{\dot{z}}$ - Heaving velocity due to moment
M_θ - Pitching displacement due to moment
$M_{\dot{\theta}}$ - Pitching velocity due to moment
θ - Pitching motion
$\dot{\theta}$ - Pitch velocity
$\ddot{\theta}$ - Pitch acceleration

z	-	Heave displacement
$\dot{z}$	-	Heave velocity
$\ddot{z}$	-	Heave acceleration
ω	-	Natural frequency
T	-	Kinetic energy
U	-	Potential energy
K_u	-	Heaving structural stiffness
K_θ	-	Pitching structural stiffness
E	-	Young’s modulus
I	-	Second moment of inertia
J	-	Torsion constant
G	-	Modulus of rigidity
m	-	Mass per unit area of wing
s	-	Wing semi-span
x_f	-	Flexural axis
f	-	Volume fraction
p	-	Design domain
x	-	Vector of design variable
x_{min}	-	Vector of minimum relative densities
N	-	Number of elements

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Aeroelasticity is the subject that describes the interaction between aerodynamic, inertia and elastic forces. From the Collar's aeroelastic triangle in Figure 1.1, the aerodynamic stability, structural vibrations and static aeroelasticity is a results from the interaction between two different types of forces. However, three forces are required for the dynamics aeroelasticity to occur.

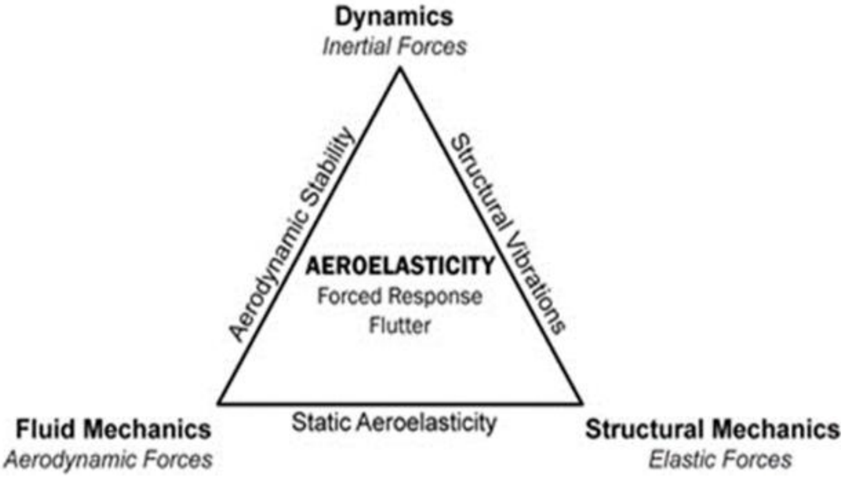

Figure 1.1: Collar's aeroelastic triangle.

Aeroelastic phenomena can be classified into static and dynamic. The static aeroelastic effects can also lead to a reduction in the effectiveness of the control surfaces and eventually to the phenomenon of control reversal.

Dynamic aeroelasticity on the other hand is concerned with the oscillatory effects of the aeroelastic interactions. A major area of interest in dynamic aeroelasticity is the potentially catastrophic phenomenon of flutter which involves two or more modes of vibrations from the coupling of aerodynamic, inertial and elastic forces (Wright & Cooper, 2007).

For the past few decades, aeroelastic behaviour has been studied by a lot of researchers to prevent the catastrophic failure from happening and the results can be obtained from previous research work which covers a lot of aspects in providing the best method to predict flutter as well as providing the parameters which affect the flutter behaviour.

1.2 Problem Statement

Due to the high strength to weight ratio, composites materials has been used in the aircraft designs (Chang, Yang, Wang, & Wang, 2010; Georgiades & Banerjee, 2016; Guo, Banerjee, & Cheung, 2003). One of the advantages of using composites is the ability to design the material properties according to the orientation, which can be useful in overcoming aeroelastic problems such as divergence, flutter and gust response. Various researches have been carried out to understand the effects of composites laminate configuration towards flutter, especially the ply orientation. There is however scarce information on the effects of composites layout such as internal structure configuration towards flutter characteristics.

As mentioned earlier, flutter may lead to the catastrophic failure if the aircraft does not have stiffer structures. Therefore, this study covered the parametric analysis on the material and the factors which affect the flutter for swept wing of composites UAV.

1.3 Objectives

The objective of this work is to understand the effects of the various spar and rib design configurations and materials parameters on the flutter characteristics of a composite UAV wing structure.

1.4 Scope of Study

This work used UTM CAMAR unmanned aerial vehicle (UAV) wing as a case study and considered only the major internal structural components namely the spars and the ribs and neglecting other additional structures such as stringers and others. Combinations of up to two spars and two ribs placed at various positions were considered. The material used for the study was limited to carbon-epoxy composites as used in UTM CAMAR.

1.5 Overview of the Study

The study of the flutter analysis begin by discussing the phenomenon of the flutter in Chapter 1, as well as the objectives, problem statement and the scope of the study.

The detailed literature review is discussed in Chapter 2, where the initial derivation of the flutter equation is laid out and the basic concept to apply the flutter analysis which is binary aeroelastic model and the final full aeroelastic motion equation are shown in the chapter.

The methodology of the study is discussed in Chapter 3, where the step by step of solving and analysing the flutter throughout the study starting from the literature review until obtaining the flutter velocity through the MATLAB script file, cama_20kg.m are discussed in the chapter.

In Chapter 4, the flutter analysis process is outlined by discussing the initial step of starting the analysis as well as the constant parameter and the physical parameters of the case studies which is UTM CAMAR 20 kg.

Later, in Chapter 5, the results of each of the topology optimisation and the parametric studies are discussed by plotting and tabulating the results.

The conclusion and recommendation of future studies are discussed in Chapter 6 by relating the parameters that is being set in the study with the results obtained.

REFERENCES

Balabanov, V., & Haftka, R. (1996). Topology optimization of transport wing internal structure. *Journal of Aircraft, 33*(1), 232-233.

Bendsoe, M. P., & Sigmund, O. (1999). Material interpolations in topology optimization *Arch. Appl. Mech, 69*, 635-654.

Bisplinghoff, R. L., & Ashley, H. (1962). *Principle of Aeroelasticity*: Dover.

Bisplinghoff, R. L., Ashley, H., & Halfman, R. L. (1996). *Aeroelasticity*: Dover.

Castro, S. G. P., Guimaraes, T. A. M., Rade, D. A., & Donadon, M. V. (2016). Flutter of stiffened composite panels considering the stiffener's base as a structural element. *Composite Structures*.

Chang, N., Yang, W., Wang, J., & Wang, W. (2010). *Design optimization of composite wing box for flutter and stiffness*. Paper presented at the 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, Orlando, Florida.

Fung, Y. (1969). *An Introduction to the Theory of Aeroelastcity*: Dover.

Georgiades, G. A., & Banerjee, J. R. (2016). Flutter prediction for composite wings using parametric studies. *AIAA Journal, 35*(4).

Guo, S. J., Banerjee, J. R., & Cheung, C. W. (2003). The effect of laminate lay-up on the flutter speed of composite wings. *Journal of Aerospace Engineering, 217*(3), 115-122.

Hancock, G. J., Simpson, A., & Wright, J. R. (1985). On the teaching of classical flutter. *Aeronautical Journal, 89*, 285-305.

Housner, J. M., & Stein, M. (1974). Flutter analysis of swept-wing subsonic aircraft with parameter studies of composite wings. *NASA TN D-7539*.

James, K. A., Kennedy, G. J., & Martins, J. R. R. A. (2014). Concurrent aerostructural topology optimization of a wing box. *Computers & Structures, 134*, 1-17. doi: http://dx.doi.org/10.1016/j.compstruc.2013.12.007

Kameyama, M., & Fukunaga, H. (2005). Optimum design of composite plate wings for aeroelastic characteristics using lamination parameters. *Journal of Computers and Structures*.

Kobayashi, M., Pedro, H., Kolanay, R., & Reich, G. (2009). On a cellular division method for aircraft structural design. *Aeronautical Journal, 113*(1150), 821-831.

Koo, K. N., & Lee, I. (1994). Aeroelastic behavior of a composite plate wing with structural damping. *Journal of Computers and Structures, 50*(2), 167-176.

Krog, L., & Tucker, A. (2004). *Topology Optimiation of Aircraft Wing Box Ribs* Paper presented at the 10th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Albany, New York.

Locatelli, D., Mulani, S., & Kapania, R. (2011). Wing-box weight optimization using curvilinear spars and rib (SpaRibs). *Journal of Aircraft, 48*(5), 1671-1684.

Megson, T. H. G. (2007). *Aircraft Structures for Engineering Student* (4th ed.).

Mozaffari-Jovin, S., Firouz-Abadi, R. D., & Roshanian, J. (2014). Flutter of wings involving a locally distributed flexible control surface. *Journal of Sound and Vibration*.

Rammohan, B., Rajagopal, S., Prabhakaran, V., & Singh, P. (2005). Parametric studies on flutter speed of composite laminates. *NaCoMM*.

Sigmund, O. (2001). A 99 line topology optimization code written in Matlab. *Struct. Multidisc. Optim, 21*(120-127).

Theodorsen, T. (1934). General theory of aerodynamic instability and the mechanism of flutter *NACA Technical Report 496*.

Theodorsen, T., & Garrick, I. E. (1940). Nonstationary Flow about a Wing-Aileron-Tab Combination Including Aerodynamic Balance *NACA Technical Report*

Theodorsen, T., & Garrick, I. E. (1942). Nonstationry flow about a wing-aileron-tab combination including aerodynamic balance *NACA Technical Report 736*.

Woolston, D. S., & Huckel, V. (1954). A calculation study of wing-aileron flutter in two degrees of freedom for two-dimensional supersonic flow *NACA Technical Report 3160*.

Wright, J. R., & Cooper, J. E. (2007). *Introduction to Aircraft Aeroelasticity*: John Wiley & Sons.