Flutter Analysis of Unmanned Aerial Vehicle Wing

Mohankumar.N [1], Dr. S.Periyasamy[2]
[2] Assistant Professor, Dept Of Mechanical Engineering,
[1, 2] Government College Of Technology,
Coimbatore, Tamilnadu, India

Abstract- *Flutter is a dangerous phenomenon encountered in flexible structures subjected to aerodynamic forces. Flutter occurs as a result of interactions between aerodynamics, stiffness and inertial forces on a structure. To prevent this instability, the interaction among these forces must be properly understood. Accordingly, a mathematical formulation for flutter analysis has developed form a simple wing model. The model has formulated to illustrate the dynamic characteristics of aeroelastic systems. For UAV the basic design parameters are considered. A computer code in MATLAB has developed for determining the critical flutter speeds and associated flutter frequencies. Then this method can be extended to the flutter analysis of the actual wing with control surface effects.*

Keywords- Aeroelastic, Flutter, Instability, MATLAB, UAV.

I. INTRODUCTION

Flutter is the dynamic instability where the structure extracts kinetic energy from air and this energy cannot be dissipated by structural damping. As a result of this the aircraft component vibrates with increasing amplitude. The excitations due to small disturbances create vibrations on the lifting surfaces (i.e. wing or tail) of the aircrafts. The energy is dissipated due the damping of the structure at low speeds and as a result of this energy dissipation the vibrations decay in time. At a critical speed, the oscillations can just maintain itself; a steady amplitude motion can be observed and the vibrations do not decay anymore. This critical speed is called the flutter speed. Above the flutter speed any small disturbance, even engine noise, creates oscillations increasing in time and leads to catastrophic failure. In flutter phenomenon, the structure gains energy from the flow.

II. MATHEMATICAL FORMULATION

Consider the three-dimensional aerofoil shown in figure 1 with the elastic axis positioned a distance ec aft of the aerodynamic centre and ab aft of the mid chord.

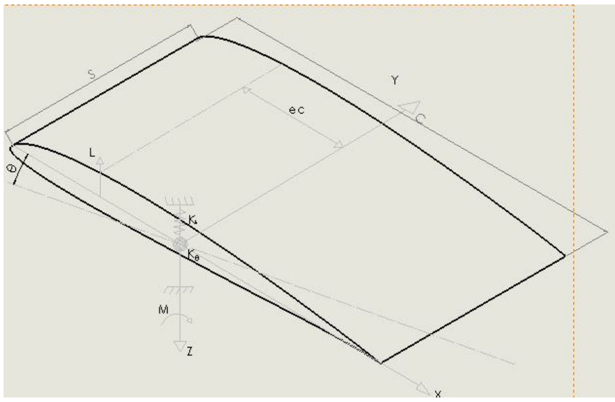

Fig. 1: Airfoil configuration with and without the control surface (aileron)

The governing equations of motion for the aeroelastic system has the following homogenous form [2].

$$\mathbf{A}\ddot{q} + (\rho V\mathbf{B} + \mathbf{D})\dot{q} + (\rho V^2\mathbf{C} + \mathbf{E})\mathbf{q} = \mathbf{0} \qquad (1)$$

Where **A,B,C,D,E** are the structural inertia, aerodynamic damping, aerodynamic stiffness, structural damping and structural stiffness matrices respectively and **q** are the coordinates (original/ generalized) defining degrees of freedom. Refer to Appendix A for detailed variable definitions associated with the aeroelastic model. The structural damping is assumed to be negligible (**D**= **0**) in the subsequent analysis. The system matrices (without the control surface) corresponding to (1) for this configuration, is obtained from equation 11.16 of [2] is as follow,

$$\mathbf{A} = \begin{bmatrix} I_K & I_{K\theta} \\ I_{K\theta} & I_\theta \end{bmatrix} \quad \mathbf{B} = \begin{bmatrix} \frac{cS^3 a_w}{4} & 0 \\ \frac{-eC^2S^2 a_w}{4} & \frac{-c^3 s}{8} M_\theta \end{bmatrix}$$

$$\mathbf{C} = \rho V^2 \begin{bmatrix} 0 & \frac{CS^2 a_w}{4} \\ 0 & \frac{-eC^2 S a_w}{2} \end{bmatrix} \quad \mathbf{E} = \begin{bmatrix} K_K & 0 \\ 0 & K_\theta \end{bmatrix} \qquad (2)$$

III. NUMERICAL METHOD

From Equation (2), we get by assuming that force as F cosωt.

$$I_k\ddot{k} + I_{k\theta}\ddot{\theta} + \rho vcs^2 a_w/4\,\dot{k} + k_k k + \rho v^2 ecs^2 a_w/4\,\theta = F\cos\omega t \qquad (3)$$

$$I_{k\theta}\ddot{k} + I_\theta\ddot{\theta} - \rho vec^2 s^2 a_w/4\,\dot{k} - \rho vc^3 s/8\, M_{\theta}\dot{\theta} + [-\rho v^2\, ec^2\, sa_w/2 + k_\theta]\,\theta = F\cos\omega t \qquad (4)$$

In order to use the MATLAB program ode23, the two coupled second-order differential equations, Equation (3),(4) are to be expressed as a system of coupled first-order differential equations. For this, we introduce new variables y_1, y_2, y_3 and y_4.

$$k = y_1$$
$$\dot{k} = y_2$$
$$\theta = y_3$$
$$\dot{\theta} = y_4 \qquad (5)$$

By substituting Equation (5) in (3),(4) the equation is transferred as follows

$$\dot{y_1} = y_2$$
$$\dot{y_2} = 1/I_k\,[F\cos\omega t - Ike\dot{y_4} - \rho vcs^2 a_w/4\, y_2 - kky_1 + \rho v^2 ecs^2 a_w/4\, y_3]$$
$$\dot{y_3} = y_4 \qquad (6)$$
$$\dot{y_4} = 1/I_\theta\,[F\cos\omega t - I_{k\theta}\dot{y_2} + \rho vec^2 s^2 a_w/4\, y_2 + \rho vc^3 s/8\, M_\theta\, y_4 - [-\rho v^2\, ec^2\, sa_w/2 + k_\theta]\, y_3]$$

IV. RESULT

These results have been generated from MAT code to the velocity 30m/s to 190m/s.

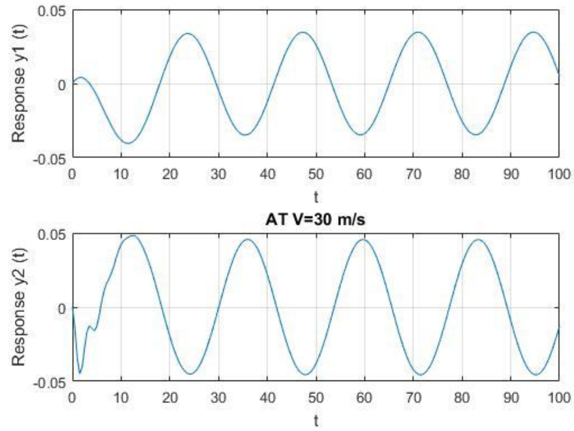

Fig 2 Graphical Representation Of Time Response Of The Wing Model At V=30m/s

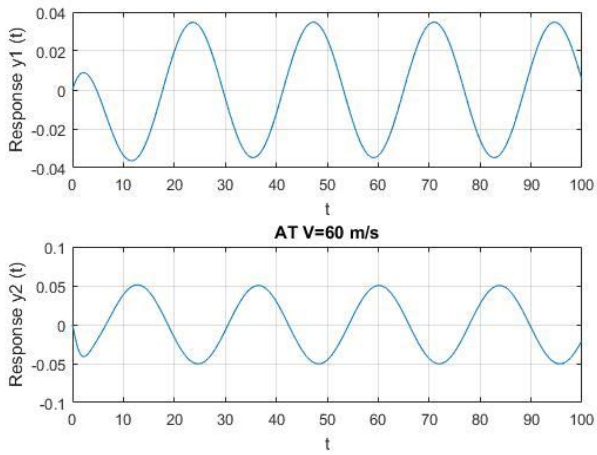

Fig 3 Graphical Representation Of Time Response Of The Wing Model At V=60m/s

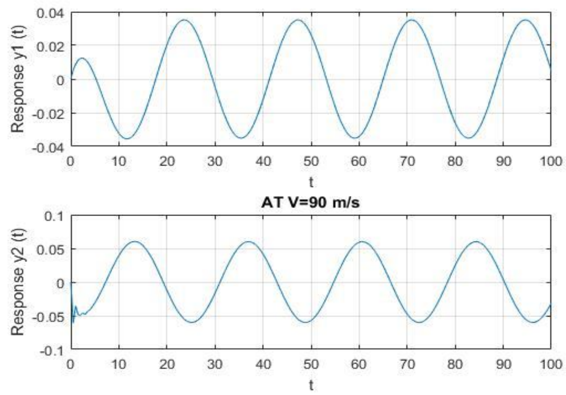

Fig 4 Graphical Representation Of Time Response Of The Wing Model At V=90m/

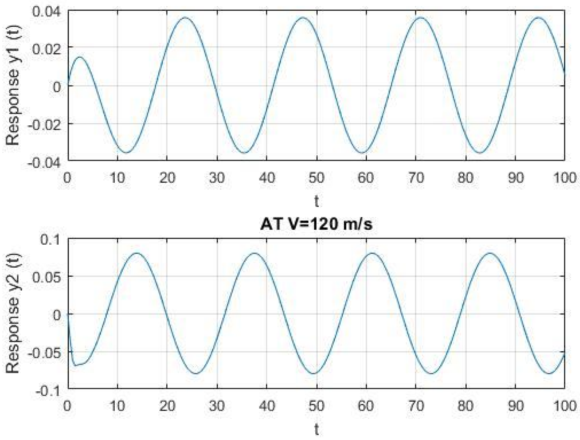

Fig 5 Graphical Representation Of Time Response Of The Wing Model At V=120m/s

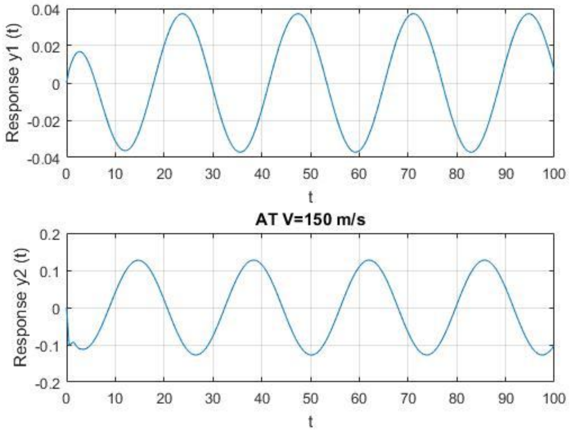

Fig 6 Graphical Representation Of Time Response Of The Wing Model At V=150m/s

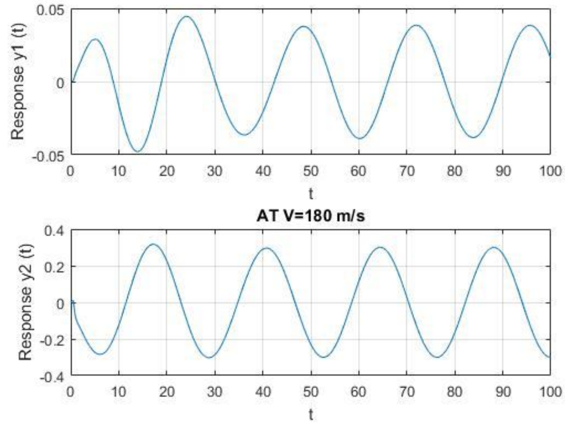

Fig 7 Graphical Representation Of Time Response Of The Wing Model At V=180m/s

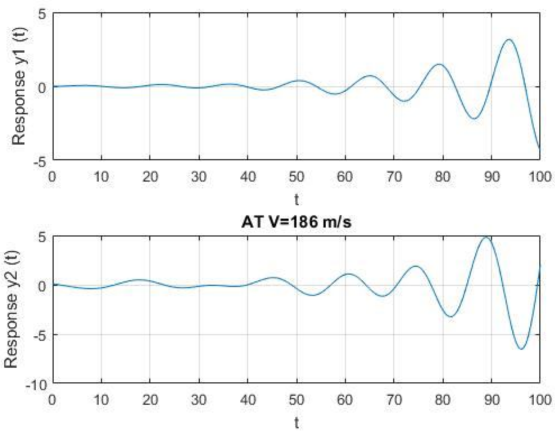

Fig 8 Graphical Representation Of Time Response Of The Wing Model At V=186m/s

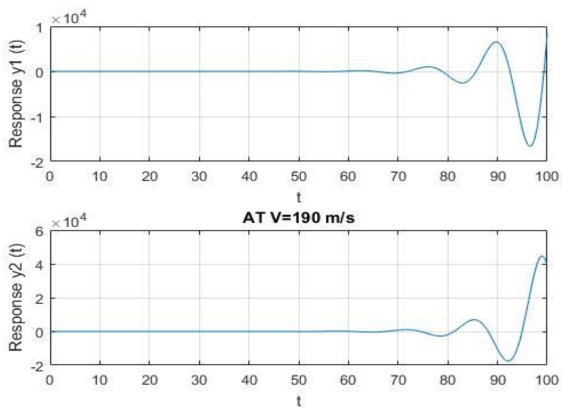

Fig 9 Graphical Representation Of Time Response Of The Wing Model At V=190m/

V. DISCUSSION

The graphs in previous section show the variation of amplitude with respect to time at different velocity. For the velocity 30m/s to 180m/s are shown in fig. 2 to 7 the response obtained is simple harmonic so that the UAV is stable. For the velocity above 180m/s the amplitude become more abrupt at some point of time are shown in fig 8 and 9. The UAV become unstable. The velocity 180 m/s is the critical speed of UAV above which the flutter occurs. The flutter speed obtained from the present analysis of UAV binary wing model matches with the experimental flutter speed in the literatures. The comparison shows the validity of present method for flutter analysis.

VI. CONCLUSION

In the present analysis of UAV wing, classical binary model was used. The wing was subjected to forced vibration flutter analysis by applying aerodynamics force. The flutter analysis of the two degree of freedom wing was performed. The present analysis gives a conservative value identified form MATLAB code. For the present wing shape and the parameter the flutter speed was determined as 180 m/s. The quasi-steady method can easily be extended to the control surface assembly. The flutter speed of different materials wing can be obtained by changing the mass matrix parameter so that it will be easy to select the best material for wing.

REFERENCES

[1] Cheng-Chi Wang, Chieh-Li Chen and Her-TerngYau, 2014, “Bifurcation and Chaotic Analysis of Aeroelastic Systems”, AMSE, vol.9 / 021004, pp.1-13. [DOI:10.1115/1.4025124]

[2] Wright, J.R. and Cooper, J.E., 2007, “Introduction to Aircraft Aeroelasticity and Loads”, John Wiley

[3] John W. Edwards and Carol D. Wieseman, 2008, “Flutter and Divergence Analysis Using the Generalized Aeroelastic Analysis Method”, J.AIRCRAFT, Vol.45.No.3, pp.906-915. [DOI: 10.2514/1.30078]

[4] Robert L. Clark, John A. Rule and Robert E. Richard, 2001, “Genetic Spatial Optimization of Active Elements on an Aeroelastic Delta Wing”, ASME, Vol.123 pp.466-471. [DOI: 10.1115/1.1389458]

[5] Wright, J.R., Wong, J., Cooper J.E. and Dimitriadis, G., 2004, “On the use of control surface excitation in flutter testing”, ASME, G217, pp.317-332.

[6] Arion Pons and Stefanie Gutschmidt, 2016, “Aeroelastic Flutter of Continuous Systems: A Generalized Laplace Transform Method”, ASME, Vol.83 / 0810051, pp.1-8. [DOI: 10.1115/1.4033597]

[7] P. C. Chen, 2000, “Damping Perturbation Method for Flutter Solution: The g-Method”, AIAA, Vol.38.No.9, pp.1519-1524.

[8] Sebastian Heinze and Dan Borglund, 2008, “Robust Flutter Analysis Considering Mode Shape Variations”, J.AIRCRAFT, Vol.45.No.3, pp.1070-1074 [DOI: 10.2514/1.28728]

[9] Michaël H. L. Hounjet, 2010, “Verification of H Flutter Analysis”, J.AIRCRAFT, Vol. 47, No. 6, pp.2168-2173 [DOI: 10.2514/1.C031030]

ANNEX A
NOMENCLATURE AND VALUES USED FOR NUMERICAL ANALYSIS

Variable	Definition	Value
S	Semi-span (m)	7.5
C	Chord (m)	2
E	Eccentricity between flexural axis & aero center (m)	0.15
P	Air Density (kg/m^3)	1.225
x_f	Flexural axis (m)	0.48c
x_{cm}	Mass axis (m)	0.5c
M	Mass per unit area (kgm^2)	200
i_k	Moment of inertia (kgm^2)	28125
i_θ	Moment of inertia (kgm^2)	502.4
$i_{k\theta}$	Product moment of inertia (kgm^2)	225
K_k	Flap Stiffness (N-m/rad)	$i_k\,(10\text{x}2\pi)^2$
K_θ	Pitch stiffness (N-m/rad)	$i_\theta\,(5\text{x}2\pi)^2$
M_θ	Non-dimensional pitch damping derivative	-1.2
a_w	Lift curve slope	2π
F	Force(N)	50
ω	Natural frequency (rad/sec)	50
T	Time(sec)	1-100
A	Two-dimensional lift curve slope	6.283
V	Velocity (m/s)	1-180