Modeling and Flutter Analysis of a Three Dimensional Box-Wing using Wagner Unsteady Aerodynamic Model

Amir Hossein Ghasemikaram[1], Abbas Mazidi[1*], Seyed Ahmad Fazelzadeh[2]

[1]Mechanical Engineering School, Yazd University
[2]Mechanical Engineering School, Shiraz University

ABSTRACT

In this paper, the three dimensional model of a box wing configuration is derived by a semi-analytical approach and the aeroelastic behavior is studied. So far, the flutter characteristics have been studied on the typical wing sections or via a whole lot more time and cost in the professional software. The winglet is modeled by two longitudinal and torsional springs and in order to simulate the effect of the winglet on the dynamic behavior, two ends of the springs are placed on the elastic axis of the sections. The governing equations are extracted via Hamilton's principle and in order to apply the aerodynamic forces, Wagner unsteady model is considered. To transform the linear partial integro-differential equations into a set of ordinary differential equations, the mathematical techniques are employed. For the purpose of validation, the flutter values of the box wing are obtained by MSC NASTRAN and the proposed numerical procedure. The effects of the sweep angles and the winglet rigidity on the flutter are investigated. The results reveal that increasing the sweep angles and the chord ratio, enhances the flutter speed, remarkably. Furthermore, increasing the torsional rigidity of the winglet is more significant than the longitudinal rigidity on the flutter.

KEYWORDS

Flutter, Box-Wing, Wagner unsteady model

---

[*] Corresponding Author: Email: Amazidi@yazd.ac.ir

1. Introduction

Box Wing Aircraft (BWA) is introduced by Prandtl in 1924. The BWA decreases the induced drag compared to the conventional wings. A reduction of induced drag in the BWA has significant influence on the airplane weight and performance.

In recent years, most of the researchers have been focused on design of the BWA configurations and there is not yet a comprehensive literature studying the flutter of box wings. In the present effort, aeroelastic modeling and flutter analysis of a 3-D BWA configuration are carried out using Wagner unsteady aerodynamic model.

2. Methodology

One way to derive the governing equations in complex dynamic systems is to use several intermediate coordinate systems. The BWA is included front wing, rear wing and winglet that connects to the wings tip [1]. The intermediate coordinate systems are placed on the airplane's center of gravity, root and tip of wings. Figure 1 shows a schematic of the coordinate systems [2].

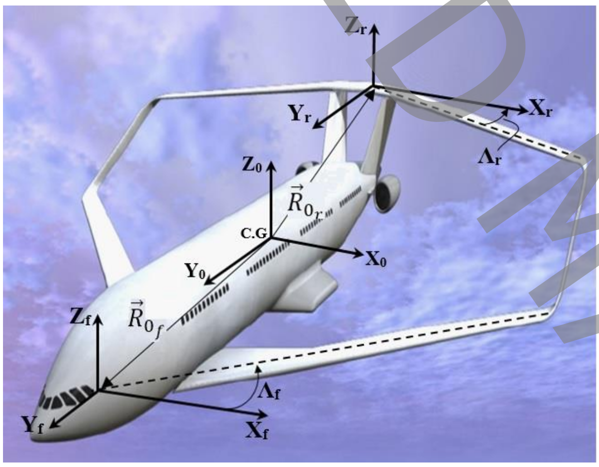


Figure 1. A schematic of the coordinate systems

Furthermore, when the systems include concentrated discrete nodes, can utilize Delta Dirac function in order to apply the properties of nodes in the governing equations. Also, in order to simulate the torsional and longitudinal behavior of the winglet, is used two linear springs [3]. The equations are obtained via Hamilton's variational principle and are as coupled partial integral differential equations (PIDEs). The equations include parameter-dependent and time-dependent integral parts which Dirac Delta function is multiplied by itself several times in the parameter-dependent terms. Furthermore, the time-dependent terms are presented in Wagner unsteady model that is utilized to apply the aerodynamic forces and moments.

3. Numerical solution

The governing equations are solved by a novel procedure as following steps:

- Develop the parameter-dependent terms: A new class of generalized functions was developed by NASA report [4]. The functions can derive from hyperbolic tangent and Gaussian families which the hyperbolic tangent family is utilized in the present work. Therefore, the parameter-dependent terms can be developed using the mentioned relations and by part integral method.
- Eliminate the time-dependent terms**:** Using by part integral method and some mathematical techniques as Ref. [5], the time-dependent terms are eliminated from the equations developed in the previous step.
- Transform PDEs to ODEs**:** The expanded equations from the previous steps, will be as partial differential equations (PDEs) and transformed to ordinary differential equations (ODEs) using the assumed modes method [6].

For the determination of flutter, the problem is reduced to that of finding the eigenvalues of the coefficient matrix in the state-space. The eigenvalue ω is a continuous function of the air speed U_∞. For $U_\infty \neq \cdot$, ω is in general a complex value, $\omega = \mathrm{Re}(\omega) + i\ \mathrm{Im}(\omega)$. When $\mathrm{Re}(\omega) = \cdot$ and $\mathrm{Im}(\omega) \neq \cdot$, the wing is said to be in critical flutter condition and when $\mathrm{Re}(\omega) = \cdot$ and simultaneously $\mathrm{Im}(\omega) = \cdot$, the wing is said to be in critical divergence condition.

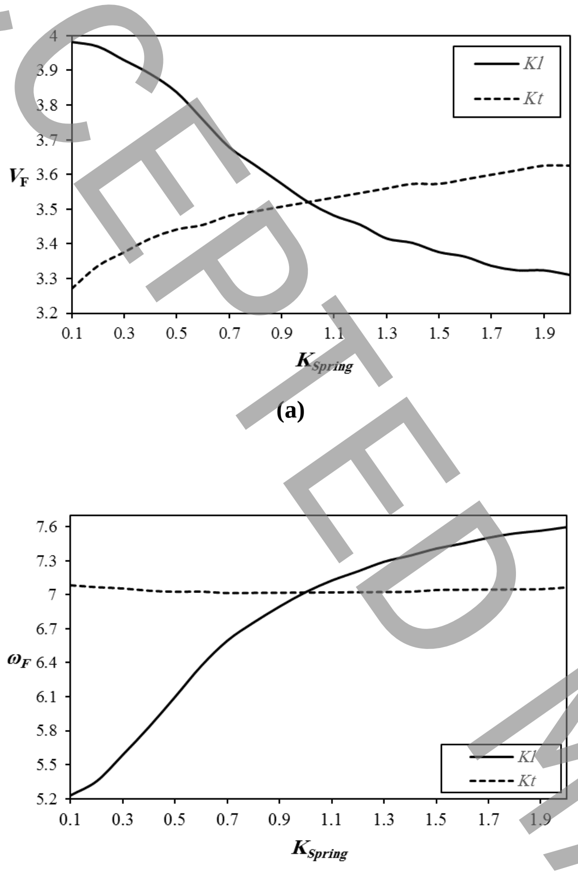
4. Results and Discussion

There is no numerical solution or experimental data for the studied model so far. Therefore in this work, the flutter analyses of the BWA is performed in MSC NASTRAN software and the results are compared as in Tables 1. As can be seen, a good agreement is reported.

Table 1. Validation of the flutter speed for the BWA

Component	Method	V_F (m/s)	ω_F (Hz)
Front Wing	Wagner Theory	287	4.58
	NASTRAN	289	3.29
Rear Wing	Wagner Theory	274	6.89
	NASTRAN	271	6.75
Box-Wing	Wagner Theory	269	6.55
	NASTRAN	270	4.63

The effect of torsional and longitudinal rigidity of the winglet on flutter frequency and speed is demonstrated in Figure 2. Increasing the longitudinal rigidity, diminish the flutter speed and enhances the flutter frequency. On the other hand, increasing the torsional rigidity, develops the flutter speed and has no effect on the flutter frequency.



(a)

(b)

Figure 1. The variation of (a) Flutter velocity (b) Flutter frequency vs. stiffness of the longitudinal and torsional springs

5. Conclusions

The extracted equations included several parameter/time-dependent integral parts. Furthermore, Dirac Delta function was multiplied by itself several times. The validation revealed that can utilize the procedure for the solution of PIDEs which include generalized functions, parameter-dependent and time-dependent integral parts.

The effects of some important parameters are studied on the flutter such as sweep angle, and torsional and longitudinal rigidity of the winglet. The results reveal that increasing the sweep angles and the chord ratio, enhances the flutter speed, remarkably. Furthermore, increasing the torsional rigidity of the winglet is more significant than the longitudinal rigidity on the flutter.

6. References

[1] D.J.D.F.t.u.F. Schiktanz, Master Thesis, Hamburg, HAW Hamburg, Conceptual design of a medium range box wing aircraft, (2011).
[2] S.A. Fazelzadeh, A.H. Ghasemi, A.J.I.J.o.A. Mazidi, Vibration, Aeroelastic analysis of unrestrained aircraft wing with external stores under roll maneuver, 21(3) (2016) 327-333.
[3] S.A. Fazelzadeh, D. Scholz, A. Mazidi, M.I. Friswell, Flutter characteristics of typical wing sections of a box wing aircraft configuration, (2018).
[4] R.C. Costen, Products of some generalized functions, National Aeronautics and Space Administration, 1967.
[5] S. Shams, H. Haddadpour, M.S. Lahidjani, M. Kheiri, An analytical method in computational aeroelasticity based on Wagner function, in: 25th International Congress of the Aeronautical Science, Hamburg, Germany, 2006.
[6] S. Fazelzadeh, A. Mazidi, Nonlinear aeroelastic analysis of bending-torsion wings subjected to a transverse follower force, (2011).