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Active Flutter Control of a Swept Wing with an Engine by Using Piezoelectric Actuators

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ABSTRACT: In this paper, active flutter control of a swept wing with an engine is carried out. The aircraft wing is considered as a uniform swept cantilever beam carrying an engine. The piezoelectric layers are attached to the wing to control the vibrations. To simulate aerodynamic loads, the Theodorsen model is used. The equations of motion determined via Hamilton's variational principle, are transformed to a set of ordinary differential equations through the assumed mode method. Lyapunov controller is used to control the system. Effects of design parameters like engine thrust, location and mass and the wing sweep angle, are evaluated on the flutter speed. The control system has been applied at the flutter situation. Results show that the control system can substantially suppress the vibration in all cases. According to the results, the length of the piezoelectric layers affects the speed of the flutter and the flutter speed increases by increasing the length of these layers. Also, according to the influence of the Lyapunov gains on the performance of the system, it is necessary to select these values carefully in order for control system to have the best performance for different values of the system parameters.

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1- Introduction

Nowadays, due to the tendency to reduce fuel consumption, more light materials are employed in aircraft manufacture. The use of these materials in the aircraft design has increased the flexibility of airplane components, such as wing, which makes the aeroelastic analysis more prominent. In the meantime, the aircraft wing is one of the most important aeroelastic structures. Due to the flexibility of the wing, the large deformations created in this structure, combined with aerodynamic forces, can lead to complicated aeroelastic problems. Flutter is a serious aeroelastic problem that should be studied in the design of the aircraft. This phenomenon is caused by the interaction of aerodynamic forces, elastic forces and the inertia forces and could cause a sudden structural destruction [1].

The harmful effects of flutter vibration can be suppressed by employing an active control system. Recently, due to low weight, small dimensions, high stiffness, and quick response of piezoelectric materials, there has been a growing interest in the use of these materials in control systems, as actuators and sensors. Piezoelectric transducers are broadly used in vibration control applications. In this research, complete aeroelastic model of a swept wing with an engine are obtained and after detecting the flutter boundaries, an active controller with piezoelectric materials is applied to suppress the vibration of the wing in flutter condition.

2- System Modeling

In this study, piezoelectric layers are used for control of the wing vibration. Position of sensors and actuators on the beam (equivalent to Wing) is shown in Fig. 1.

Governing equations and boundary conditions are obtained by using Hamilton's principle [2]. Furthermore, Thodorsen's aerodynamic model is used to simulate aerodynamic loads. [3].

For numerical solution of the aeroelastic governing equations, the assume mode method is used. To this end, generalized coordinates are represented by means of series of trial functions multiplied by time dependent generalized coordinates [2]. Six bending modes in *w* direction and six torsion modes are considered in the assume mode method to transform governing equations to a set of ordinary differential equations

The governing equations of the system with regard to piezoelectric layers after using assume mode method are derived as:

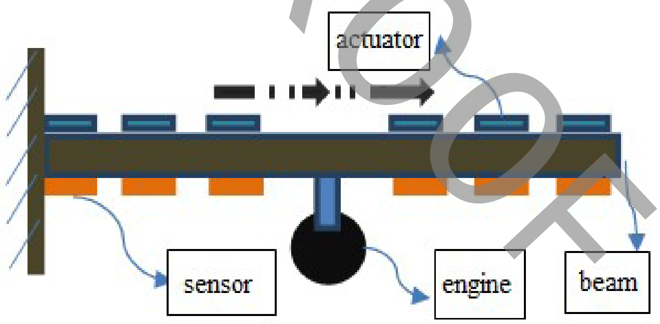

Figure 1. Position of sensors and actuators on the beam.

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$$M_{12*12}\ddot{q} + C_{12*12}\dot{q} + K_{12*12}q = K_{elast_a} v_{a}\rceil_{12*1}$$
$$q = \begin{bmatrix} q_1 \\ q_2 \end{bmatrix}_{12*1} \qquad (1)$$

The vector v_a represents the voltage of piezoelectric actuators and q is the overall vector of generalized coordinates.
To suppress the vibration of the wing and make it stable, a Lyapunov approach controller is used. The voltages applied to the piezoelectric actuators are designed as [4]:

$$v_a = -K_d \dot{v}_s - K_p v_s$$
$$v_s = K^{-1}_{pelect} K^{T}_{elast_s} q \qquad (2)$$

where v_s is the vector of sensors voltages and K_d, K_p are controller gains.

3- Results and Discussion

In order to validate, results of reference [4] are used. The reference beam has an external mass under external force and carrying piezoelectric layers as sensors and actuators. The variation f the first two resonant frequencies with respect to dimensionless follower force are plotted for the wing and compared with this reference (in case ζ^2=0) in Fig. 2. Results reveal that the correlation between the present results and the reference results is excellent.
Following dimensionless parameters are used for ease of displaying the results [5].

$$P_i = \frac{p_i L^2}{\sqrt{GJEI_y}}, X_e = \frac{x_e}{L}, Y_e = \frac{y_e}{b}, \eta_e = \frac{M_e}{mL} \qquad (3)$$

Dimensionless tip deflection is plotted For $P_i = 1,\ \eta_e = 0.1,\ \lambda = \frac{\pi}{4},\ X_e = 0.3,$ and $Y_e = -0.25$ in Fig. 3.
It can be seen in this figure that the wing tip deflection has been acceptably suppressed by applying voltages to the piezoelectric actuators. This illustrates that control system is able to suppress the vibration.
To demonstrate the voltage of piezoelectric layers, the voltages of first, seventh and twelfth sensors and actuators are plotted in Figs. 4 and 5.

4- Conclusions

In this study, the piezoelectric layers are used to suppress the vibrations of a swept wing with an engine. Governing equations of motion are derived based on Hamilton's principle. These equations are solved through the assumed mode method by numerical integration on the domain. The voltage applied to piezoelectric layers is also based on the Lyapunov controller. The dimensionless tip deflection in terms of time is plotted to evaluate the performance of the control system. The obtained results indicate that the control system is reliable. Also according to the results, with suppression of the wing vibration, voltages of piezoelectric sensors and actuators approach to zero over the time.

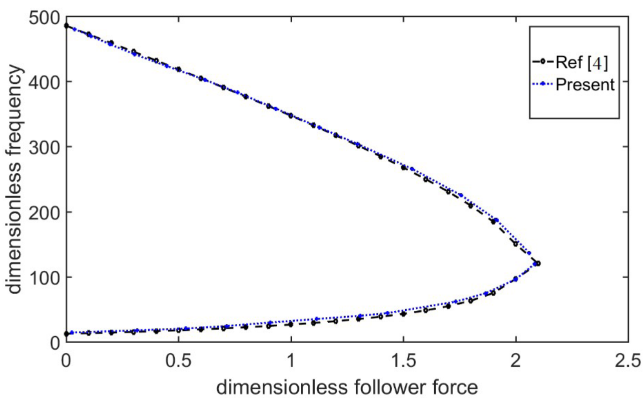

Figure 2. Validation of results.

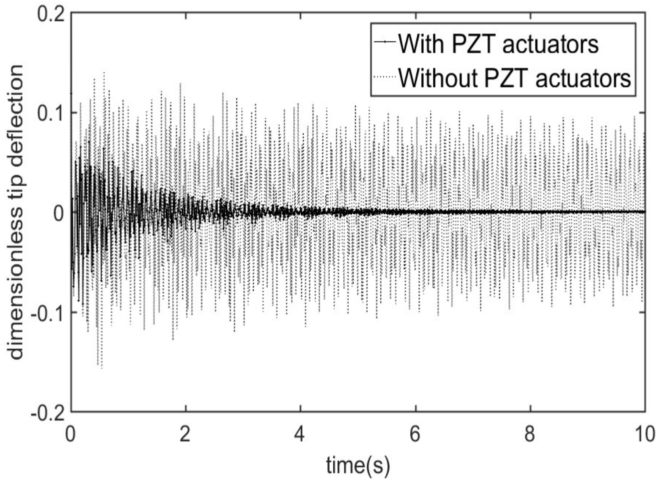

Figure 3. Dimensionless tip deflection in terms of time.

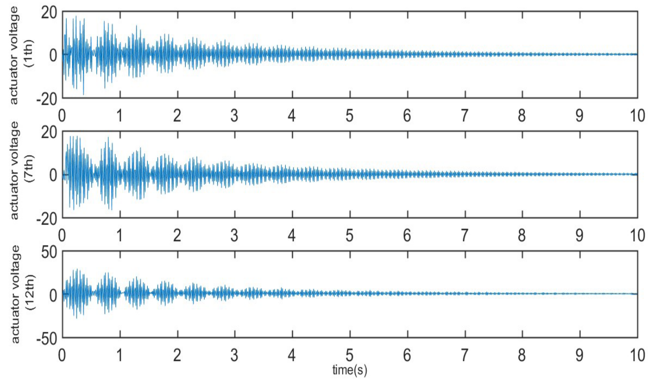

Figure 4. Voltage of first, seventh and twelfth actuator in terms of time.

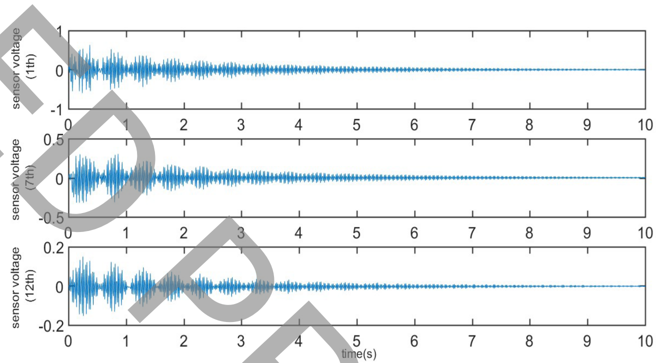

Figure 5. Voltage of first, seventh and twelfth sensor in term of time.

References

[1] Fazelzadeh, Seyed Ahmad, and Mohammad Azadi. "Active Nonlinear Aeroelastic Control for Damping Vibration of a Tank Attached to the Wing." Amirkabir university of technology: Fifteenth Annual Mechanical Conference (International), 2007 ISME, 2007.

[2] Hodges, Dewey H., and E. H. Dowell. "Nonlinear equations of motion for the elastic bending and torsion of twisted nonuniform rotor blades." (1974).

[3] Hodges, Dewey H., and G. Alvin Pierce. Introduction to Structural Dynamics and Aeroelasticity. Vol. 15. cambridge university press, 2011. Web. 20 June 2017.

[4] Azadi, Vahid, et al. "Active control of an FGM beam under follower force with piezoelectric sensors/actuators." International Journal of Structural Stability and Dynamics 14.02 (2014): 1350063.

[5] Mazidi, A., and S. A. Fazelzadeh. "Aeroelastic modeling and flutter prediction of swept wings carrying twin powered engines." Journal of Aerospace Engineering 26.3 (2011): 586-593