Experimental Validation of Improving Aircraft Rolling Power Using Piezoelectric Actuators

LI Min[1], CHEN Wei-min[2], GUAN De[1], LI Wei[1]

(1. School of Aeronautics Science and Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100083, China)

(2. Division of Engineering Sciences, Institute of Mechanics, CAS, Beijing 100080, China)

Abstract: Piezoelectric actuators are mounted on both sides of a rectangular wing model. Possibility of the improvement of aircraft rolling power is investigated. All experiment projects, including designing the wind tunnel model, checking the material constants, measuring the natural frequencies and checking the effects of actuators, guarantee the correctness and precision of the finite element model. The wind tunnel experiment results show that the calculations coincide with the experiments. The feasibility of fictitious control surface is validated.

Key words: piezoelectric actuator; rolling power; wind tunnel experiment

利用压电驱动器改善飞机横滚性能的试验验证. 李敏, 陈伟民, 管德, 李维. 中国航空学报(英文版), 2005, 18(2): 108- 115.

摘 要: 利用分布粘帖在矩形机翼上下两面的压电驱动器, 探索使用该类结构提高飞行器横滚能力的可能性。通过风洞模型设计、材料性能测试、模型固有特性测试、压电柔度矩阵测试等试验项目, 保证了有限元模型的计算精度, 最终通过模型的风洞试验验证了利用气动弹性效应, 获得了附加升力与横滚力矩的方案。该原理性试验说明利用分布式压电驱动器改善横滚性能是可行的。

关键词: 压电驱动器; 横滚性能; 风洞试验

文章编号: 1000-9361(2005)02-0108-08 中图分类号: V217^{+}.33 文献标识码: A

Traditionally, a pilot provides a rolling maneuver for turning of the aircraft with an aileron system by rotation of trailing edge control surfaces on the right and left wing in a differential sense. The aileron system increases the lift on one wing and decreases lift on the opposite wing, resulting in a rolling moment producing the rolling maneuver. However, if the aircraft is operating at high dynamic pressures where the deformation of the wing is significant, the rolling rate is reduced until the aileron reversal occurs. The design to avoid aileron reversal will result in increasing the weight of wing.

Recent advancements in actuation and sensing technology have invigorated the exploration of adaptive aerospace structures. In the last 10 years several investigations were conducted to understand the application of smart materials to control of air vehicle structures. The smart materials based actuation system are attractive because of their characteristics high-energy densities. Ehlers and Weisshaar[1] conducted a comprehensive analytical study to understand how active control using piezoelectric (PZT) patches to reshape the wing can improve aerodynamic performance and control static aeroelastic characteristics such as divergence. Lin, Crawley and Heeg[2] conducted a highly innovated experimental and analytical investigations to increase the aircraft flight envelop by suppressing flutter using a distributed network of piezoelectric patches. Richard and Clark[3] further investigated the flutter control of a delta wing. Knot, Eastep, Koloney, *et al*[4-8] published a series of papers about the improvement of aircraft rolling power by using piezoelectric actuators as the struts of the ribs of a wing, and the fictitious control surface (FCS)

Received date: 2004-10-25; Revision received date: 2005-01-26

Foundation item: Aeronautical Science Foundation of China (03A51052); National Defence Preplan(413130308)

technique, using elastic wing twist and camber to achieve a specified rolling rate at all dynamic pressures, was put forward. However, these studies, and several like them[9-11], have shown that a network of sensors and actuators can be used to control a structure and improve the flight performance of air vehicles. NASA and the Defense Advanced Research Projects Agency have adopted the term of "morphing aircraft" to describe the application of the adaptive structures, among other technologies, for this purpose.

The authors[11] adopted a rectangular wing model with distributed piezoelectric actuators. The difference between the model with aileron deflection and the model without aileron was studied. The analytical results showed that these two cases are substantial different. For aileron deflection case, the aeroelastic effect is disadvantageous, so the structural stiffness should be high until the electric voltage is not necessary. But for the case of FCS, the aeroelastic effect is advantageous that means lower structural stiffness can lead to lower voltage. As the subsequent research, in the present investigation a wind tunnel model is designed to validate the calculation results. The ground experiment and the wind tunnel experiment are implemented and the investigations show that the calculation results coincide with the experiment results and the feasibility of FCS is validated.

1 Analytical Models and Equations

1.1 Analytical models

As in Fig. 1, a rectangular wing model with aspect ratio 4.0 is used. The analytical model is composed of a number of rectangular aerodynamic panels. The aerodynamic load of each panel is located at 1/4 chord point at mid-span of the panel (pressure point) and the boundary condition is fulfilled at 3/4 chord point at mid-span of the panel (downwash point).

Structurally, the model is a plate with equal thickness, and the piezoelectric plates are bounded on both sides. The structure coordinate is consistent with the aerodynamic coordinate. Finite element model as shown in Fig. 2 is constructed by bending plate element with 4 nodes and 5 degrees of freedom for each node. The distribution of piezoelectric plates is consistent with that of aerodynamic panels, as shown in Fig. 2.

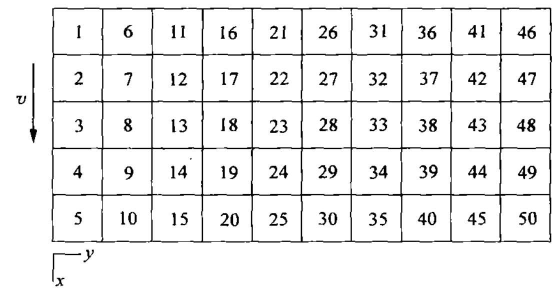

Fig. 1 Aerodynamic panels of the wing model

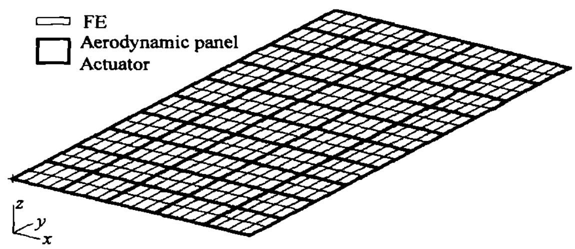

Fig. 2 Finite element mode of the wing model

The material of wing model is LY12CZ whose elastic modulus $E_m = 70$ GPa, Poisson ratio $\mu_m = 0.3$ and mass density $\rho_m = 2700$ kg/m^3. The parameters of the piezoelectric actuator used are $E_p = 70$ GPa, $\mu_p = 0.3$ and $\rho_p = 7000$ kg/m^3, and the piezoelectric constants $d_{31} = d_{32}$, being 250×10^{-12} m/V.

1.2 Static aeroelastic equations

The governing equations of static aeroelasticity are as follows:

$$\alpha_f = \alpha_0 + \alpha_e + \alpha_V \quad (1)$$

$$\alpha_f = (\boldsymbol{I} - q\boldsymbol{C}^{\theta z}\boldsymbol{A})^{-1}(\alpha_0 + \alpha_V) \quad (2)$$

$$\boldsymbol{F}_\theta = \boldsymbol{RA}(\boldsymbol{I} - q\boldsymbol{C}^{\theta z}\boldsymbol{A})^{-1}(\alpha_0 + \alpha_V) \quad (3)$$

where α is the column vector of angle of attack of each aerodynamic panel. Subscript 0, e and V denote the initial, elastic deformation and electric voltage of actuator, respectively. $q = \frac{1}{2}\rho_0 v^2$ is the dynamic pressure, ρ_0 is the density of air, v is the velocity of airflow. $\boldsymbol{C}^{\theta z}$ is the flexibility matrix, and