Gust Load Alleviation of Flexible Aircraft

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ABSTRACT: Concerns about aircraft gust disturbance have increased not only because of the design cases that are not primarily structural but also because of gust influence on aircraft handling qualities and flight controllability. Load alleviation system duty is reducing loads caused by a gust on aircraft. Using active control when crossing gust causes alleviation of loads on aircraft and improves ride quality. In this paper gust response of a flexible aircraft has been simulated by using the Lagrange equation and quasi-steady aerodynamics. Wing has been considered as flexible and other parts have been considered rigid. Two degrees of freedom in pitch and plunge of rigid mode have been considered and the elastic wing has been modeled as a beam with torsion and bending. Gust responses with different profiles have been analyzed. Then by using elevators and aileron gust loads have been reduced. Feedback control has been used to decrease the pitch and heave acceleration of the aircraft. Closed and open-loop response to gust has been compared and it has been shown that pitch oscillations have been damped very well by elevator. Then by using elevators and flaperon gust loads have been reduced by using neural networks adaptive controller and classic controller. Comparison has been made between closed-loop and open loop response to gust.

1- Introduction

Gust is one of the sources of critical design and fatigue loads. The gusts cause structural elastic vibrations and rigid-body motions which can result in a significant reduction of the airframe structure's life. It is due to the high level of dynamic stresses that occur during these events. However, vibrations caused by gusts may have an adverse effect on passenger comfort, pilot workload, and aircraft handling quality [1]. An active control technique called Gust Load Alleviation (GLA) can be used to minimize the adverse effects induced by the gust. This paper investigates the dynamic response of flexible aircraft to gust. Then by using control surfaces tries to alleviate gut loads on aircraft. It uses an elevator and flaperon to decrease gust effects on aircraft.

2- Methodology

A flexible aircraft (Fig. 1) has been modeled with considering pitch and plunge of a rigid body, z, and θ, and bending and torsion of elastic wing h and α.

A quasi-steady aerodynamic model has been used. By using the Lagrange equation, it is possible to obtain generalized forces Q_h and Q_α [2]:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial q_i} + \frac{\partial \bar{U}}{\partial q_i} = Q_i \ , \ i = 1,2,3,4 \tag{1}$$

$$q_1 = z, \quad q_2 = \theta, \quad q_3 = h, \quad q_4 = \alpha$$

The generalized forces of Q_i are calculated by virtual work:

$$Q_z = -L_{\mathrm{w}} + W - L_T$$
$$Q_\theta = \ell_{\mathrm{w}} L_{\mathrm{w}} + M_{E.A} - \ell_T L_T$$
$$Q_h = -L_{\mathrm{w}} \tag{2}$$
$$Q_\alpha = M_{E.A}$$

L_w and L_t are lift forces of wing and tail, l_w and l_t distance from wing and tail elastic axes to aircraft C.G respectively. $M_{E.A}$ is the moment around the elastic axis of the wing. Now by putting Q_i and arranging aerodynamic and structural forces it is possible to write:

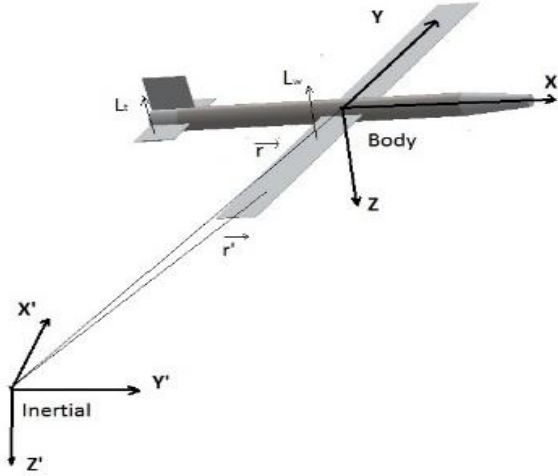*Corresponding author's email: hsadati@mut.ac.ir

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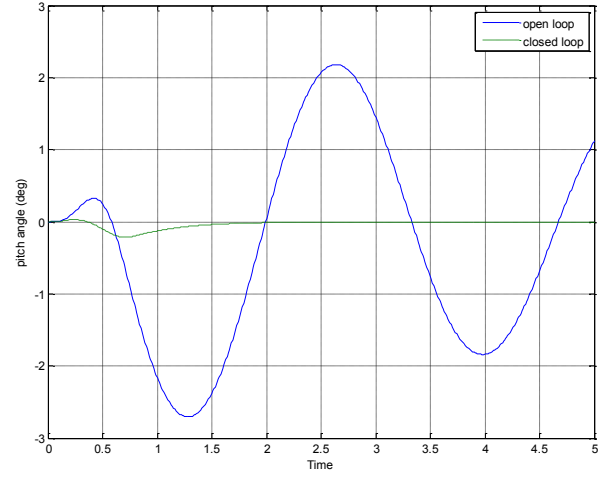**Fig. 1. Aircraft with flexible wings**

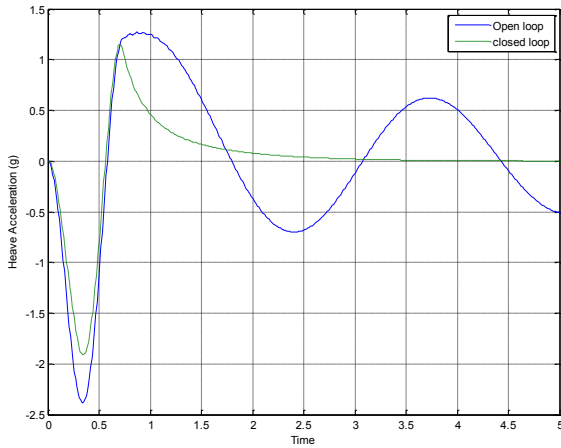**Fig. 2. Comparison of pitch response of aircraft in closed and open-loop**

Fig. 3. Comparison of heave acceleration of aircraft in closed and open-loop

$$\left(M_s + M_a\right)\ddot{q} + \left(C_s + C_a\right)\dot{q} + \left(K_a + K_s\right)q = F$$
$$q_1 = z, \quad q_2 = \theta, \quad q_3 = h, \quad q_4 = \alpha \tag{3}$$

In the above equation z and θ are rigid modes, h is bending modes of the wing, and α is torsional modes of the wing. F is composed of two elements gust and control forces:

$$F = F_{Gust} + F_{control} \tag{4}$$

$$F_{control} = BU$$
$$U = \begin{bmatrix} \delta_{elevator} & \delta_{flapeleron} \end{bmatrix} \tag{5}$$

In the above equation, U denotes control command, $\delta_{elevator}$, elevator rotation, and $\delta_{flapeleron}$ flaperon rotation.

3- Results and Discussion

The 1-cosine gust [3] with a vertical velocity of 20 m/s and a gust length of 110 m has been applied to the flexible airplane with a velocity of 150 m/s. The wing has been considered flexible. Pitch response to gust has been shown for closed and open-loop in Fig. 2.

Gust causes aircraft pitch nose down then nose up and this behavior repeats with lower amplitude. But with controller after nose down aircraft slightly begins to nose up and reaches zero attitude. As it is seen controller has been able to damp and control oscillations of aircraft and brings back vehicles to its stable position in a short time. Fig. 3 shows heave acceleration. The controller reduces heave acceleration and damps oscillations.

In order to alleviate gust load on aircraft, a Proportional Integral Derivative (PID) and adaptive neural network controller has been used. In Fig. 4 pitch response of adaptive neural network and PID, control methods have been compared. As it is seen adaptive neural network method shows better results than PID. Fig. 5 shows heave acceleration results for these controllers. Both have similar trends but as before adaptive neural network, methods damps acceleration faster than the PID method.

Fig. 6 shows wing bending due to gust. Adaptive neural network methods damp wing bending faster than the PID method.
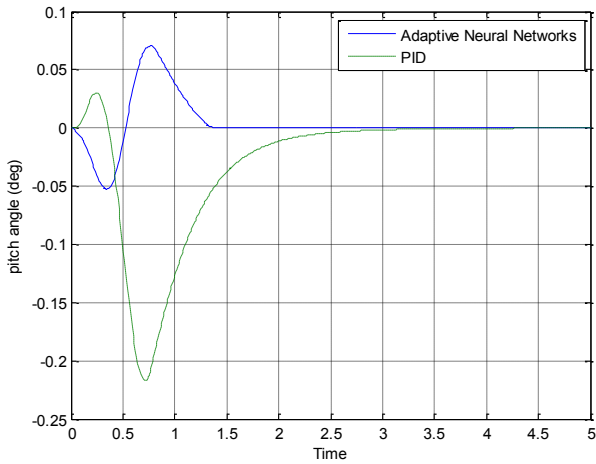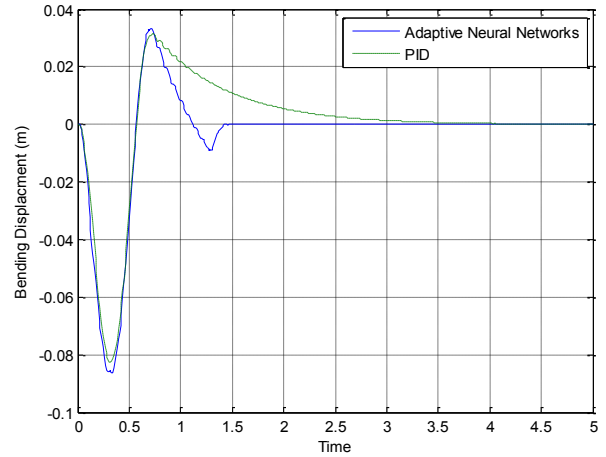
Fig. 4. Pitch angle versus time
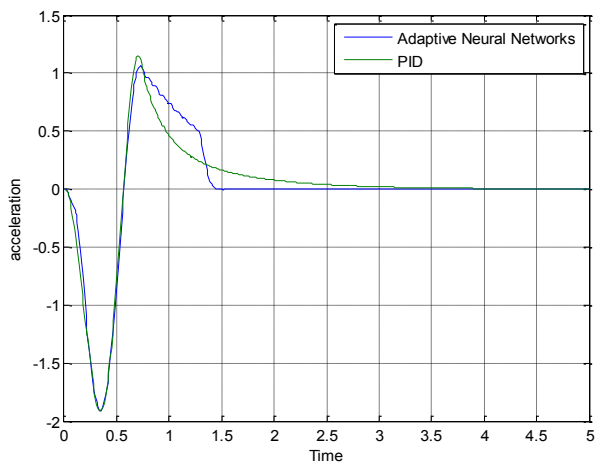

Fig. 6. Wing bending versus time

Fig. 5. Heave acceleration (g) versus time

4- Conclusions

In this paper, the dynamic response of a flexible aircraft to 1-cosine gust has been studied. Then by using neural adaptive controller gust loads have been reduced. Elevator has been used to control pitch oscillations and alleviate the heave acceleration of the aircraft. A comparison has been made between PID, and neural adaptive controller, which shows neural adaptive controller has better results than PID.

References

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[3] J.R. Wright, J.E. Cooper, Introduction to aircraft aeroelasticity and loads, John Wiley & Sons, 2008.