Comparison of the passive and active control
gust alleviation of a flying-wing aircraft

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Abstract: Various gust alleviation technologies including passive and active methods have been investigated. This research is focused on the gust response analysis of the flying-wing aircraft with a gust alleviation device. Both passive and active approaches are investigated. Longitudinal analysis is involved in the gust response analysis. The model is longitudinally trimmed before gust response analysis. The result shows that efficiency is related to the frequency of deflection motion. The active control approach is more efficient than the passive gust control approach.

1 Introduction

In order to improve the aerodynamic performance of air vehicles, especially for a high-altitude long-endurance aircraft, a high aspect ratio wing is an ideal option. At the same time, the wing structure becomes more flexible and more sensitive to aeroelastic effects, such as flutter and gust response. Composite materials offer high-specific modulus and strength, and also a design option for laminate tailoring. For a tailless flying-wing aircraft, the weak longitudinal stability aggravates this kind of effect. Hence, gust response is one of the most critical concerns in the wing structure design and flight stability analysis. Some models actually experience extreme challenges when subjected to gust load [1].

Various gust alleviation technologies including passive and active methods have been investigated in previous research and some other applications. For composite wing structure, aeroelastic tailoring, which can be treated as one of the passive technologies, is a very effective approach. Much previous research has been focused on this area to achieve better aeroelastic characteristics and structural weight saving. Different design variables have been considered in structural optimisation problems, such as laminate stacking sequence [2, 3], ply orientation [4, 5] and thickness [6], structural geometric configuration [7, 8] and so on.

A few specific designed devices were proposed to alleviate the gust response of aircraft in a passive way. A typical feature is that those passive alleviation devices are entirely composed of mechanics or structural parts without any electric element.

Active control technology is another means employed in advanced aircraft design. Control surfaces, normally located in the leading edge and the trailing edge, are usually used and actuated in response to gust load in an active manner. Control laws are developed to alleviate the dynamic response in an active way for various vehicles based on their own characteristics.

Compared with an active approach, the passive or adaptive way is much simpler and potentially more reliable. However, it may not be as efficient as the active approach. For this reason, the current research is focused on the gust alleviation efficiency comparison of passive and active control technologies of the gust alleviation device.

2 Gust alleviation device concept

An aircraft platform of tailless flying-wing configuration as presented in Fig. 1 was taken as the study case in this investigation. Design data for the aircraft are given in Table 1. The configuration of the wing with a large sweep angle and high aspect ratio presents the most challenging case for a dynamic response and aeroelastic stability analysis.

3 Gust response analyses with longitudinal rigid body motion

Normally, an aircraft with tailless flying-wing configuration is statically unstable. Hence an elevon and active control were employed to meet the dynamic stability requirement. The following section presents an investigation into the PGAD efficiency considering the interaction between gust response and stability.

Table 1 Main design parameters

| Parameter                        | Value   |
|----------------------------------|---------|
| wing semi span, m                | 31.14   |
| fuselage length, m               | 14.7    |
| Maximum Take-Off Mass (MTOM) (full fuel, kg) | 55,350  |
| Operational Empty Mass (OEM) (empty fuel, kg) | 23,350  |
| sweep angle, deg                | 30      |
| cruise altitude, km             | 18.3    |
Longitudinal analysis, which is relatively simple but typical and important, was involved in the current study.

3.1 Modelling

As shown in Fig. 3, an elevon was added to the Finite Element (FE) model to trim the aircraft to level flight condition. The elevon was modelled by the rigid beam and concentrated mass (80 kg) with its hinge line located at 80% of the local chord. The aerodynamic load was calculated based on the mesh shown in Fig. 4, in which the elevon surface (shown in grey) was 4000 mm span length and 780 mm chord length.

3.2 Engineering modification

Since the stiffness information of the actuator of the elevon was unavailable, an empirical value was applied to reduce the rotation frequency to a practical range. The frequency needed to be high enough to avoid the coupling between the elevon rotation and wing bending, which would decrease the flutter speed significantly. According to modal analysis, the elevon rotation frequency of 30.5 Hz was not involved in the undesirable coupling and was unlikely to cause aeroelastic instability problem.

The trim condition was set to 0.3 Mach with MTOM at sea level, the typical gust case. It should be noted that the engine attachment point was moved forward 4 m to balance approximately the nose up moment. Without moving the engine position, the elevon would not have been able to trim the aircraft by itself even using the maximum deflection angle of 30°. Finally, the aircraft was trimmed at the angle of attack (AoA) of −1.3° with a small elevon deflection of 0.17°. The abnormal negative AoA, which was in accordance with the Computational Fluid Dynamics (CFD) result of −1° [9], was because of the fairly high lift coefficient of the NACA4415 aerofoil ($C_l \approx 0.5$).

4 Results and discussion

4.1 Passive case study

Once the aircraft was trimmed longitudinally, the gust response analysis could proceed forward appropriately with both heave and pitching modes included. In this case, the gust-induced wing tip deflection relative to wing root with heave and pitching motion of the aircraft is shown in Fig. 5. The PGAD passive rotation in response to the gust load is shown in Fig. 6. ‘Don’ and ‘Doff’ indicate the conditions of device free and device clamped, respectively. As shown in Fig. 7, the 17.3% gust response reduction in terms of wing tip elastic deflection achieved with the PGAD.
4.2 Active case study

To make a comparison of the passive gust alleviation with active control, a simple open loop active control of the PGAD was studied. In this case, the wing root was clamped and the gust was set at the same frequency of 0.5 and 0.8 Hz, respectively. An enforced deflection, with identical amplitude as the passive motion of the device and exactly opposite phase as gust input, was applied on the PGAD to simulate the active control case.

The response results of the wing are presented in Figs. 8–11. Curve legend ‘Don Uz’, ‘Doff Uz’ and ‘act Uz’ mean the wing tip deflection in the Z-direction with the device free, device clamped and active control applied, respectively. ‘Theta’ is the PGAD rotation relative to the wing tip. The angular limit to PGAD rotation was removed to give a clear picture.

In the 0.5 Hz gust case, the gust response was reduced by 15.8% for the active device and 8.2% for the passive device, see Fig. 8. The active approach is more efficient than the passive way.

In the 0.8 Hz gust case, the reduction was 8.4 and 5.8% for the active and passive device, respectively, see Fig. 10. So, the active controlled device achieved more reduction in the 0.5 and 0.8 Hz gust input. This is mainly because the specified rotation angle of the active device is larger and the phase much different from the PGAD. It can be observed in Fig. 11 that a clear phase delay of the PGAD occurs for the passive maximum nose down deflection compared with the active device.

5 Conclusion

This research was focused on the gust response analysis of the flying-wing aircraft with a gust alleviation device. Both passive and active device are effective in gust response alleviation. The result shows that efficiency is related to the frequency of deflection motion. The active control with the gust alleviation device actuated in exactly opposite phase to the gust load tended to more efficient as shown in a simplified open-loop active control simulation by enforced gust alleviation device rotation.

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