Engineering Notes

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Airspeed Control under Wind Shear Conditions

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Nomenclature

u = airspeed perturbation
X_u = stability derivative, $(\partial X/\partial u)/m$
ζ = damping ratio
τ_a = time constant of airspeed mode
τ_p = time constant of phugoid amplitude
ω_n = undamped natural frequency

Introduction

IN Ref. 1, Abzug presented an approximate stability analysis of an aircraft under the influence of wind shear. The objective of the current Note is to justify the assumptions used and to extend that analysis to discuss the implications to pilot control of an aircraft on landing approach.

Discussion

For a conventional aircraft the longitudinal motion can be separated into two distinct modes. The short period mode consists of angle-of-attack and pitch attitude variations and is well damped, while the phugoid consists of lightly damped variations in airspeed and pitch attitude. The common approximation for the phugoid mode gives a system damping of

$$2\zeta\omega_n = -X_u$$

from which the time constant of the oscillatory phugoid amplitude envelope is

$$\tau_p = -2/X_u$$

Now, Abzug showed that if the pitch attitude was held constant, the classical modes became an approximate "angle of attack short period" and an approximate "airspeed phugoid" mode. The time constant of this aperiodic airspeed mode is

$$\tau_a = -1/X_u$$

i.e., half the time constant of a classical phugoid. The two different responses are compared in Fig. 1, with a time scale corresponding to the jet transport cited in Ref. 1. It is seen that even with the reduced time constant the aperiodic mode does not give the pilot any appearance of airspeed stability, whereas the oscillatory mode shows a significant initial reduction in the airspeed perturbation. It is suggested that this apparent lack of airspeed stability in the aperiodic mode would induce overcontrol, i.e., larger power changes than necessary to correct an airspeed transient.

The aperiodic mode resulted from the assumption that the pilot or automatic pilot holds the pitch attitude constant. In practice, either would use the pitch attitude to control the flight path and maintain the glideslope angle. However, it may safely be assumed that the time constant of pitch attitude control is an order of magnitude less than the airspeed mode. Thus, the normal pilot or autopilot action of tightly controlling pitch attitude to maintain the glideslope is equivalent to holding attitude constant and is expected to generate the aperiodic airspeed mode.

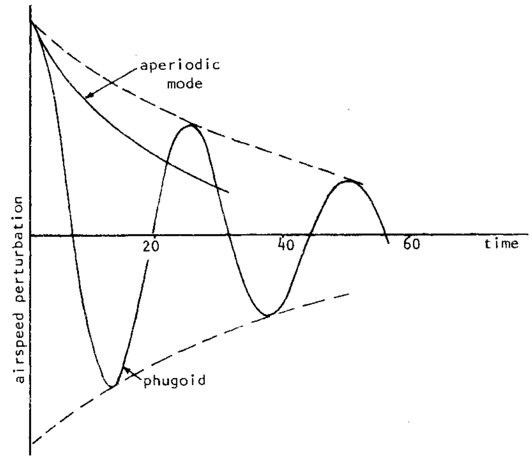

Fig. 1 Comparison of aperiodic airspeed mode with uncontrolled phugoid response.

Wind shears constitute one source of airspeed transient that can be very critical in the landing approach. For example, an increase in head wind causes an increase in airspeed and requires a reduction in thrust to control the airspeed. However, the longer term effect of an increase in head wind is to require an increase in thrust. Thus any overcontrol of the initial airspeed perturbation would make the longer term glideslope control that much harder. This situation occurred in an aircraft accident reported in Ref. 2. The aircraft flew through a decreasing tail wind (equivalent to an increasing head wind) from 500 ft to 200 ft altitude. The autopilot/autothrottle continually reduced thrust to hold airspeed. The pilot took over control to make a manual landing at a point where the aircraft had a gross thrust deficiency in a head wind. The pilot was unable to prevent a short landing.

Conclusions

1) Following a wind shear in the landing approach the normal pilot control of pitch attitude to maintain glideslope leads to the aperiodic airspeed mode presented by Abzug.

2) Even with a smaller time constant, the aperiodic airspeed mode has the appearance to the pilot of less airspeed stability than the uncontrolled phugoid, and thus causes a potential overcontrol problem.

3) Control of increases in airspeed, reductions in power, should be handled very carefully in wind shear conditions.

References

[1] Abzug, M. J., "Airspeed Stability under Wind Shear Conditions," *Journal of Aircraft*, Vol. 14, March 1977, pp. 311-312.

[2] Anon., "NTSB Assays Iberia Accident at Logan," *Aviation Week and Space Technology*, April 7, 1975, pp. 54-59; also "Wind Factor Studied in Iberia Crash," *Aviation Week and Space Technology*, April 14, 1975, pp. 53-56.

Received June 3, 1977; revision received Sept. 1, 1977.
Index categories: Handling Qualities, Stability, and Control; Landing Dynamics.

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