The Potential Impact of Critical Aircraft-Pilot-Couplings on the Safety of Tilt-Rotor Operations[1]

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Extended Abstract

The insidious nature of aircraft-pilot-couplings (APCs) can lead to remarkable, and difficult to predict, flight behaviour. A common characteristic is the pilot applying strong control to constrain flight-path or attitude, with the result that the more weakly-controlled flight dynamics are driven unstable. The author has analysed the problem of the loss of speed stability under flight-path constraint for rotary- and fixed-wing aircraft in Refs 1–3, citing several fatal accidents. This presentation extends this analysis to tiltrotor aircraft, using a FLIGHTLAB model of the XV-15 research aircraft (FXV-15). The root cause of the problem is the pilot or automatic flight control system attempting to control flight-path with cyclic or elevator when flying below the minimum power speed; a flight-physics interpretation is that speed instability occurs because the effective drag derivative X_{ueff}, changes sign. Strong flight-path control destroys the normally stable phugoid and forces the aircraft to fly along a sky-rail on the back-side of the drag-curve. The effective drag derivative then takes the form;

$$X_{ueff} = X_u - \frac{Z_u}{Z_w}[X_w - \frac{g}{U_e}] \qquad (1)$$

Figure 1 shows eigenvalue loci for the FXV-125 in helicopter mode, comparing pitch attitude and vertical velocity feedback to pilot's stick for 55kts (back-side) and 75kts (front-side) flight conditions. Attitude feedback is stabilising but, of course, does not maintain flight-path. Vertical velocity (flight-path) feedback destabilises the surge mode at the 55kts condition but not at 75kts. The short-period mode is also de-stabilised by flight-path control, an aspect discussed in more detail in the presentation. Results for the FXV-15 in conversion and airplane modes will also be presented.

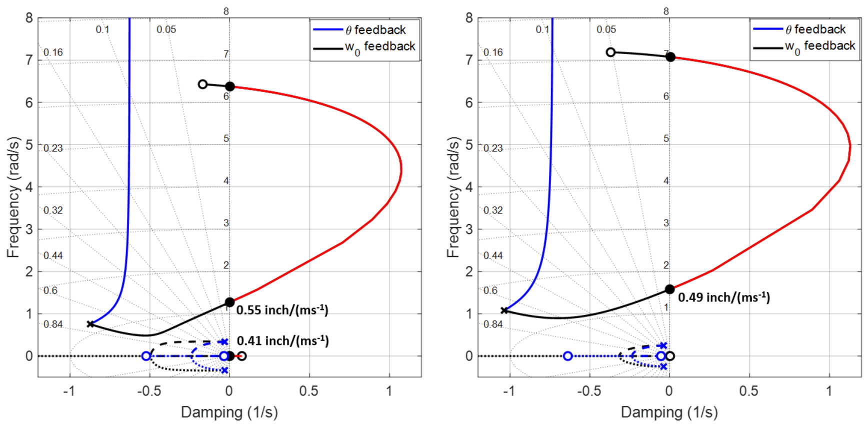

Figure 1 Eigenvalue loci for the FXV-15 in Helicopter-mode; comparison of theta and vertical velocity feedback at 55kts (left) and 75kts (right)

Less well understood is the problem of the loss of directional stability under bank angle constraint, a handling qualities deficiency that emerged during the early developments of swept-wing aircraft (Ref 4). The problem relates to the adverse aileron-yaw, leading to a change of sign of the effective directional stability, N_{veff}, under the action of strong control using aileron or, more generally, lateral control (X_a) i.e. N_{Xa}<0.

$$N_{veff} = N_v - \frac{N_{Xa}}{L_{Xa}} L_v \qquad (2)$$

The FXV-15 exhibits a mild level of adverse yaw but insufficient to cause a reversal of sign of N_{veff} and consequent aircraft-pilot-coupling under strong roll control. The author has investigated the scenario where a coupling between aileron and differential collective pitch (DCP) is included to vary the extent of adverse yaw.

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Figure 2 shows a comparison of eigenvalue loci with (right, coupling = -0.1deg/deg) and without (left) coupling. With increased adverse-yaw from the coupling, the roll is increasingly supressed and the yaw-sway mode is destabilised, as with the surge mode under flight-path control.

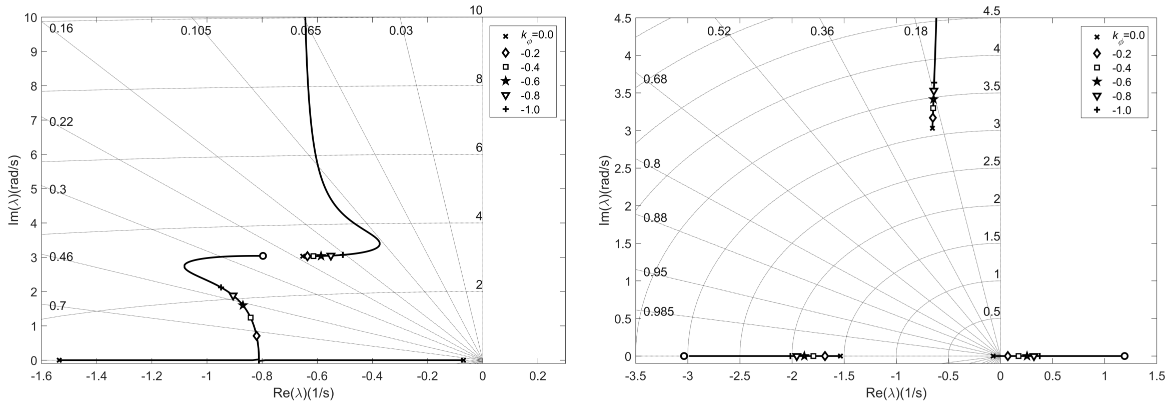

Figure 2 Eigenvalue loci for the FXV-15 in airplane mode under feedback of roll angle to aileron; with no coupling to DCP (left) and coupling to DCP (right) (Ref. 1)

In both cases, strong control of flight-path in H-mode and roll attitude in A-mode, the consequence is an aircraft-pilot-coupling, with control by the pilot or automatic control system dramatically changing the low-frequency dynamics of the closed-loop aircraft-pilot system. These problems are not new; nor are the understandings of the underlying aeronautical physics. Neumark (Ref 5) and Pinsker (Ref 4) developed the basic physics behind the couplings more than 50 years ago. Then, the author and his supervisor developed these basics into a APC theory as described in Ref 6.

In the presentation, the author will present the theory relating to loss of stability under constraints, where weakly controlled dynamics can dominate the impact on handling qualities. The application to tiltrotor aircraft reveals a range of unexpected dynamics. Vertical flight-path control in conversion mode for approach configurations will be explored to illustrate how risks associated with the loss of speed stability are mitigated by proprotor dynamics. Roll control in airplane mode will be explored to illustrate the sensitivity of horizontal flight-path and yaw stability to the extent of adverse-yaw.

In Ref 2, the author made the point that pilot training related to these adverse-couplings could be improved to prepare them for the risks and consequences of entering these danger zones. This aspect will be reinforced in the presentation, with specific recommendations for how this might be achieved.

References

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