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Further Comment on "Low-Altitude, High-Speed Handling and Riding Qualities"

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A'HARRAH'S reply[1] to my technical comment[2] could be answered point by point with a painstaking exposition of the underlying considerations deemed important by myself and others in the understanding and analysis of pilot induced oscillation (PIO). Reference 3, containing such an exposition, has been forwarded to A'Harrah for his private consumption; he may or may not consider it pertinent to his particular tests. (It does point out, citing experimental data, that when attempting to control the sinusoidal inputs that exist in a real PIO situation, the pilot describing function time delays associated with random-appearing or discrete inputs largely disappear.) In the meantime, to put our public argument to rest independently of analyses based on assumed linearized pilot models, I shall take refuge behind some recent data published by A'Harrah's colleagues.[4]

Figure 1 presents airplane characteristics investigated in the same simulation facility used by A'Harrah. These characteristics, obtained from a consistent set of airplane derivatives, are superposed on the now familiar acceptance boundary plot[5] in Fig. 1, taken directly from Ref. 4 (Fig. A7). For the identified test points, the values of $-Z_w \doteq 1/T_{\theta_2}$ were 0.937 and 1.25 for $M = 0.9$ and 1.2, respectively; in contrast, the data used to define the original acceptance boundaries, including the PIO limit lines, were obtained for $-Z_w = 3.22$, as noted in the comment.[2] Also, the stick-force/g for both Mach numbers was 1.9; and the friction band was 4 lb, as opposed to the 1.2-lb breakout of the Ref. 5 tests. The terrain-following task was similar and the gust input intensities were, if anything, greater (rms gust velocities of up to 20 fps). In addition, one series of 90-min "flights" involved four augmenter "failures" from maximum augmentation (Δ symbol) to the basic airplane (0 symbol). I quote:

> In summary, the basic airplane was only marginally unsatisfactory, so that even though the pitch augmented tests showed improved longitudinal characteristics, as would be expected, the actual failure of the augmenter caused no serious control problem. The pilot noticed that the changes from the damped to the undamped mode were felt mainly in a slight change in characteristics of the display, and also to a small degree in seat movements. *Pilot-induced oscillations were never present*[4] (my italics).

The characteristics of one of the basic airplanes lie on the "PIO limit" for 5 lb/g and the other on the limit for 1 lb/g (Fig. 1); hence, the absence of PIO's in these cases cannot be ascribed to the stick force characteristics (1.9 lb/g) that lie between these values. It seems plausible, then, to consider that perhaps the changes in $1/T_{\theta_2}$ are indeed significant. But A'Harrah argues[1] that for his PIO boundaries $1/T_{\theta_2}$ could not possibly be significant because "... for the flight conditions under discussion here, the aircraft attitude change is extremely small relative to changes in normal acceleration or rate of climb"; and later, "... the all-attitude-indicator pitch indication [is] useless to the pilot for the type of precision flying during which a PIO might be excited." However he states in Ref. 5 that "the altitude tracking (task) tended to filter the short-period dynamics per se" but that "by requesting the pilots to maneuver the aircraft as they would while making corrections in close formation flying or in any tight spot where precision control of load factor or *pitch attitude* (my italics) is critical, PIO characteristics were readily apparent. . . ." The latter statement (contained in the paper[5]) does not rule out the possibility of pitch attitude control, whereas the former (contained in the reply[1]) does.

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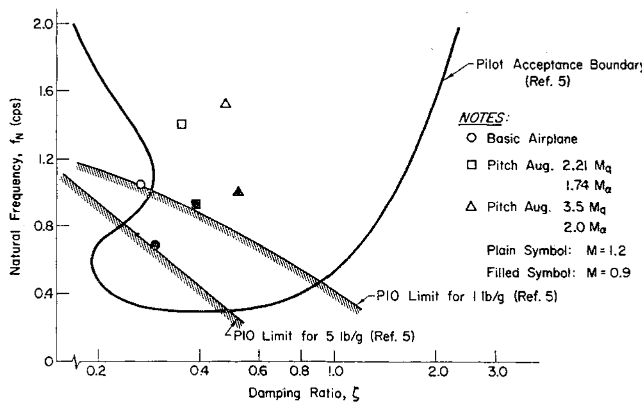

Fig. 1 Longitudinal short-period stability characteristics center stick control (Fig. A7 of Ref. 4).

For the Ref. 4 tests cited previously, the usefulness of the all-attitude-indicator (AAI) is apparently less open to question; the two pilots who commented in this connection had this to say:

Pilot 4: "Pitch indicator of AAI helped very little in pitch control. Too little sensitivity for making pitch corrections. Thought so at first, but have now learned to use it."

Pilot 8: "The aircraft responses were clearly visible on the AAI and they appeared to correspond closely to anticipated motion in 5 degrees of freedom."

Further, as noted in the Ref. 4 conclusions quoted above, the pilots *were* able to distinguish changes in short-period characteristics and the basic airframe was rated correctly (i.e., only marginally unsatisfactory, corresponding closely to its position on Fig. 1 and on its location roughly midway in the unsatisfactory lateral-directional region[4]), so the task did not apparently tend "to filter the short-period dynamics per se." This may have been due to the somewhat more sophisticated display-director commands used.

We have, then, two sets of data run in the same facility under similar environments for similar tasks. One set[4] generated by using self-consistent values of $1/T_{\theta_2}$ and $\zeta\omega$ indicated no PIO situations; the other set[5] showed a PIO region for values of $\zeta\omega$ inconsistent[2] with the *fixed* value of $1/T_{\theta_2}$ employed. In the face of these facts, the arguments advanced in Ref. 2, which go a long way toward explaining these different results, appear highly pertinent.

References

[1] A'Harrah, R. C., "Reply by author to I. L. Ashkenas," J. Aircraft 4, 223–224 (1964).

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[3] Ashkenas, I. L., Jex, H. R., and McRuer, D. T., "Pilot-induced oscillations: their cause and analysis," Northrop Corp., Norair Div., Rept. NOR 64-143 (June 20, 1964); also Systems Technology, Inc., Rept. TR-239-2 (June 20, 1964).

[4] Soliday, S. M. and B. Schohan, "A simulator investigation of pilot performance during extended periods of low-altitude, high-speed flight," NASA CR-63 (June 1964).

[5] A'Harrah, R. C., "Low-altitude, high-speed handling and riding qualities," J. Aircraft 1, 32–40 (1964).