References

[1] Mitchell, D.G. and Hoh, R.H., "Low-Order Approaches to High-Order Systems: Problems and Promises," *Journal of Guidance and Control*, Vol. 5, Sept.-Oct. 1982, pp. 482-489.

[2] A'Harrah, R.C. and Lockenour, J.L., "Wing Sizing Requirements Based on Flying Qualities in the Carrier Approach," North American Rockwell, Columbus Division, Columbus, Ohio, NR69-H-178, March 1969.

[3] A'Harrah, R.C. and Lockenour, J.L., "Approach Flying Qualities—Another Chapter," AIAA Paper 69-895, Aug. 1969.

Reply by Authors to C.R. Chalk

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WHEN we wrote that MIL-F-8785B "was developed ...for unaugmented airplanes," we did not intend to give the impression that simple feedback systems were not considered; our statement was, instead, made in the context of the title of our article.[1] In this context, "augmentation" that serves only to *modify* the response characteristics of the aircraft, *without* increasing system order, is indeed covered by MIL-F-8785B. These are aircraft which behave, as described in the background document for the more recent MIL-F-8785C,[2] "in the classical manner: response to control and disturbance inputs characterized by transfer functions of familiar form."

The statement by Chalk that MIL-F-8785B "does not properly address augmentation systems that unnecessarily create HOS" is hopefully not intended to imply that HOS are unnecessary. As Moorhouse and Woodcock[2] explain, "Prefilters, forward-loop compensation, crossfeeds, etc., are legitimate design tools which are being used on many current aircraft and indeed seem to be the norm." The Space Shuttle is an excellent example of a nonclassical aircraft utilizing complex augmentation to achieve its response characteristics in approach and landing.[3] Indeed, so-called "super-augmented" aircraft[4] such as the Shuttle may have dynamics requiring an extensive investigation to devise an appropriate set of flying qualities descriptors.

With regard to the statement by A'Harrah and Lockenour[5,6] that we quoted in our article, we recognized that n_{z_α} as used by A'Harrah and Lockenour did not necessarily represent the "real world" $n/\alpha = (U_0/g)\ (1/T_{\theta_2})$. This was the reason that we chose to look further at the original data and examine only those cases where the wing was fixed on the fuselage, thus removing any doubt as to the meaning of n_{z_α}. In doing this, we found—as clearly illustrated in our Figs. 4 and 5 (Ref. 1)—that this set of data was still consistent with the conclusions of A'Harrah and Lockenour. Those conclusions were not "misapplied" in our article, since they are even more appropriate to the set of data that we used.

The experiments conducted by A'Harrah and Lockenour contain a wealth of information on the effects of airspeed and short-period dynamics on pilot opinion ratings. We removed any questions over the meaning of A'Harrah and Lockenour's n_{z_α} by the data we presented.[1] Chalk, by listing a series of pilot ratings for $1/T_{\theta_2} = 0.8$ rad/s and $\omega_{sp}^2 = 1.6$ rad/s², attempts to refute one of the points of our article. Unfortunately, neither our earlier work[1] nor this reply allows space to present the detailed A'Harrah and Lockenour data in its entirety. Therefore we will only show here the causes of the pilot rating spread mentioned by Chalk, and in doing so will introduce more support for questioning the applicability of n/α. The data to which Chalk refers are shown in Table 1.

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Table 1 Data from Ref. 6 for $1/T_{\theta_2} = 0.8$ rad/s, $\omega_{sp}^2 = 1.6$ rad/s²

Configuration	U_0/g	PR	$M_{\delta_e}/\omega_{sp}^2$	$1/T_{\theta_2}$	ω_{sp}^2
1	10	2	0.10	0.8	1.6
(80)	(5)	(2.5)	0.10	0.8	1.6
3	2.5	6	0.10	0.8	1.6
4	1.25	10	0.10	0.8	1.6
5	20	7	0.05	0.8	1.6
6	10	3	0.05	0.8	1.6
7	5	2	0.05	0.8	1.6
9	40	10	0.025	0.8	1.6
10	20	4	0.025	0.8	1.6
11	10	4	0.025	0.8	1.6
12	5	5	0.025	0.8	1.6

Table 2 Pilot ratings for optimum combinations of U_0/g and $1/T_{\theta_2}$ (Ref. 6 data)

ω_{sp}^2	$1/T_{\theta_2}$	"Best" rating	U_0/g for "best" rating	$\frac{n}{\alpha} = \frac{U_0}{g}\frac{1}{T_{\theta_2}}$
1.6	0.8	2, 2	5, 10	4, 8
1.6	0.4	1, 1	5, 10	2, 4
1.6	0.2	1, 1, 1	5	1
1.6	0.1	5	10	1
0.8	0.8	2.8	5	4
0.8	0.4	1	10	4
0.8	0.2	1, 1	10, 20	2, 4
0.8	0.1	6	20	2

Since no pilot rating was given for configuration 2, we have included configuration 80, whose test conditions were identical. The ratings are a strong function of U_0/g, which is *not* the same as n/α. Recognizing that the pilot's control of altitude is with attitude,[1,7] the effective h/θ transfer function is

$$\frac{h}{\theta} = \frac{U_0}{s(T_{\theta_2}s+1)}$$

In this case, U_0 is airspeed and not closure (or approach) speed, which was constant for Ref. 5 at 95 knots. The A'Harrah and Lockenour data were reviewed more than a decade ago by Ashkenas,[7] who suggested that "if U_0 is made artificially high relative to the closing speed, the pilot may consider that the airplane is overly sensitive to changes in attitude; conversely, if U_0 is artificially low, the configuration could be deemed too sluggish."

Influence of U_0/g can be evaluated in the A'Harrah and Lockenour data by plotting pilot rating vs U_0/g for all the data and extracting the "best" ratings for any combination of $1/T_{\theta_2}$ and ω_{sp}^2. For example, from the list above, the pilot clearly prefers $U_0/g = 5$-10 (pilot ratings of 2 and 2). If we concentrate only on the $\omega_{sp}^2 = 1.6$ and 0.8 rad/s² cases, we find the results shown in Table 2.

Ashkenas[7] discussed similar effects from the A'Harrah and Lockenour study. The data above show that 1) pilot ratings do not correlate with n/α; 2) pilot ratings degrade for $1/T_{\theta_2} < 0.2$; and 3) ratings of 1 were given for $n/\alpha = 2$ and 1 g/rad, well within the level 2 and 3 regions in the MIL-F-8785C (Ref. 8) requirement.

References

[1] Mitchell, D.G. and Hoh, R.H., "Low-Order Approaches to High-Order Systems: Problems and Promises," *Journal of Guidance, Control, and Dynamics*, Vol. 5, Sept.-Oct. 1982, pp. 482-489.

[2]Moorhouse, D.J. and Woodcock, R.J., "Background Information and User Guide for MIL-F-8785C, Military Specification—Flying Qualities of Piloted Airplanes," AFWAL-TR-81-3109, July 1982.

[3]Myers, T.T., McRuer, D.T., and Johnston, D.E., "Space Shuttle Flying Qualities and Flight Control System Assessment," AIAA Paper 82-1608, Aug. 1982, pp. 561-570.

[4]McRuer, D., "Progress and Pitfalls in Advanced Flight Control Systems," *Advances In Guidance and Control Systems*, AGARD CP-321, Jan. 1983, pp. 1-1 through 1-17.

[5]A'Harrah, R.C. and Lockenour, J.L., "Approach Flying Qualities—Another Chapter," AIAA Paper 69-895, Aug. 1969.

[6]A'Harrah, R.C. and Lockenour, J.L., "Wing Sizing Requirements Based on Flying Qualities in the Carrier Approach," North American Rockwell, Columbus Division, Columbus, Ohio, NR69H-178, March 1969.

[7]Ashkenas, I.L., "Summary and Interpretation of Recent Longitudinal Flying Qualities Results," *Journal of Aircraft*, Vol. 8, May 1971, pp. 324-328.

[8]"Military Specification, Flying Qualities of Piloted Airplanes," MIL-F-8785C, Nov. 1980.