Technical Comments

Comment on "Low-Order Approaches to High-Order Systems: Problems and Promises"

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Introduction

MITCHELL and Hoh[1] made several statements that are not accurate. In addition, they misapplied the conclusions of A'Harrah and Lockenour[2,3] to support a claim that $1/T_{\theta_2}$ is a more appropriate criterion than n/α in correlating pilot rating data for variations of short-period frequency.

Inaccurate Statements

The following statement appears in the Introduction to Ref. 1: "The familiar Military Specification for Flying Qualities of Piloted Airplanes (MIL-F-8785B) was developed in the 1960's for unaugmented airplanes and did not account for high-order augmentation systems (HOS)." It is not true that the specification was developed for unaugmented airplanes. The requirements permit an unaugmented airplane with the c.g. as far aft as the maneuver point; i.e., the elevator surface gradient with load factor must not be unstable. With this as the starting point, all dynamic and static requirements can be met through augmentation. In fact, most of the data base for MIL-F-8785B came from variable stability airplanes which were augmented using u, $\dot{\alpha}$, α, $\dot{\beta}$, β, p, q, and r feedback and fly-by-wire commands. Although it is true that MIL-F-8785B does not properly address augmentation systems that unnecessarily create HOS, it is also true that MIL-F-8785B can be successfully used to design an augmented airplane with good flying qualities that is not a HOS.

Use of $1/T_{\theta_2}$ Instead of $n/\alpha \equiv (V/g)(1/T_{\theta_2})$

The motivation for A'Harrah and Lockenour's experiment was to challenge the minimum n/α boundaries in MIL-F-8785B for Flight Phase Category C. This is the vertical line in the specification criteria plot. It is independent of ω_n and unrelated to the CAP boundaries. A'Harrah and Lockenour had found that the minimum n/α limit had a powerful effect on the wing size required for airplanes required to make low-speed approaches.

The original draft of MIL-F-8785A did not have a minimum n/α limit. Review comments on this draft suggested that the CAP lines should be closed, for low values of n/α, by a vertical line or minimum $1/T_{\theta_2}$ limit which would be a function of true speed. The July 1968 draft of MIL-F-8785A was issued with a minimum $n/\alpha = 0.016 V_T$, where V_T is in knots. This required a minimum of $1/T_{\theta_2} = 0.305$ rad/s. Between July and October 1968, further study of then available data by the authors of MIL-F-8785B led to the conclusion that for the normal range of landing speeds, the minimum n/α boundary could be made constant and not violate existing data. The October 1968 revision was issued with constant values of the minimum n/α boundaries.

The effect of the minimum n/α limit on wing size led A'Harrah and Lockenour to perform an experiment to challenge the minimum n/α limit. They attempted to devise an experiment that would permit independent variation of V/g, $1/T_{\theta_2}$, CAP, and $n_{z_{\alpha_{wing}}}$ and would also permit using a common task as the basis for the piloted evaluation. These objectives led to an experiment involving a carrier that could speed along at -48 to 665 knots and an airplane with a variable incidence wing connected to the fuselage by a variable gearing arrangement.

One of the conclusions from Ref. 2 is "the minimum value of n_{z_α} should be specified in the manner of the July draft (i.e., a minimum value of $1/T_{\theta_2}$) rather than the subsequently recommended limitation on n_{z_α}."

A'Harrah and Lockenour[2] also commented on the validity of the CAP boundaries in MIL-F-8785B. "Influence of CAP.... This data shows a well defined degradation of pilot acceptance for CAP values less than 0.1, and indicates CAP to be a significant pilot acceptance parameter. Note that the data shown is for $1/T_{\theta_2}$ values considered satisfactory by the pilot (i.e., $1/T_{\theta_2} > 0.2$)." Note that

$$\mathrm{CAP} \equiv \ddot{\theta}_0 / n_{z_{ss}} = \frac{\omega_{sp}^2}{(V/g)/(1/T_{\theta_2})}$$

in A'Harrah and Lockenour.[2]

The validity of the data from this experiment need not be examined too closely to make the point that Mitchell and Hoh have taken a statement out of context to justify their contention that $1/T_{\theta_2}$ is a more appropriate parameter than $n/\alpha = (V/g)(1/T_{\theta_2})$.

The statement from A'Harrah and Lockenour[2] is as follows: "The fact that the pilot rating is essentially constant with n_{z_α}, even though the configurations vary from satisfactory to unacceptable, conclusively shows that n_{z_α} is not a fundamental acceptance parameter." This statement was made in the context of their experiment in which the wing was geared to the fuselage such that

$$\alpha_{\text{wing chord}} = K\alpha_{\text{fuselage reference}}$$

Therefore

$$\frac{n}{\alpha} \equiv \frac{V}{g}\frac{1}{T_{\theta_2}} = K n_{z_{\alpha_{wing}}}$$

where the gearing K was different for various groups of configurations. The n_{z_α} parameter used by A'Harrah and Lockenour was referenced to the angle of attack of the wing chord. Thus they were looking for correlation with a fictitious parameter, which is analogous to expecting pilot ratings to correlate with the flap deflection or the elevator position. This interpretation of n_{z_α} by A'Harrah and Lockenour is not consistent with the intent of MIL-F-8785B. The parameter $(V/g)(1/T_{\theta_2})$ appears in the denominator of CAP. The authors of MIL-F-8785B recognized that the steady-state ratio n/α for constant speed is essentially equal to $(V/g)/(1/T_{\theta_2})$. The n/α ratio was used in the specification because it was thought that it would be easier to evaluate from flight test data.

Mitchell and Hoh's contention that pilot rating data are correlated with $1/T_{\theta_2}$ is refuted by configurations 1-7 and 9-12 of Ref. 2. For these configurations, $\omega_{sp}^2 = 1.6$ rad/s^2 and $1/T_{\theta_2} = 0.8$ rad/s. The pilot ratings (PR) are as follows: PR = 2, 6, 10; 7, 3, 2; and 10, 4, 4, 5 for variations in V/g at three command gain values. The PR ranges from 2 to 10 for a constant value of $1/T_{\theta_2}$.

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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/s^2, 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.

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

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/s^2 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.

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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.