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Effect of Feel System Characteristics on Pilot Model Parameters

Larisa E. Zaychik*. Kirill N. Grinev. Yury P. Yashin***. Sergey A. Sorokin******

*The Central Aerohydrodynamic Institute (TsAGI), Zhukovsky, Moscow Region, Russia
(Tel: +7 495 5564155; e-mail: zaichik@tsagi.ru).
** The Central Aerohydrodynamic Institute (TsAGI), Zhukovsky, Moscow Region, Russia
(e-mail: kirill_grinev@mail.ru)
***The Central Aerohydrodynamic Institute (TsAGI), Zhukovsky, Moscow Region, Russia
(e-mail: yuyash@yandex.ru).
**** The Central Aerohydrodynamic Institute (TsAGI), Zhukovsky, Moscow Region, Russia
(e-mail: fourty-in@mail.ru)

Abstract: The paper presents recent experimental data on the effect of control manipulator feel system characteristics, such as force gradient and damping, on pilot model parameters. The analysis of the effect is conducted on the basis of limb-manipulator transfer functions identified in compensatory roll tracking task. The analysis shows that force gradient variation affects neuromuscular transfer function, demonstrating adaptation of pilot to manipulator force variation. Due to the adaptation, the limb-manipulator cutoff frequency remains constant within the force gradients assessed by the pilots as optimum. The feel system damping does not demonstrate any noticeable effect on limb-manipulator transfer function, and does not affect pilot ratings within the wide range of the characteristic variation.

Keywords: Feel system, Control manipulator, Force gradient, Damping, Pilot model, Limb-manipulator system.

1. INTRODUCTION

Most handling quality studies deal with aircraft dynamic characteristics. Manipulator feel characteristics are least often considered by researchers although their effect on aircraft handling qualities and flight safety is noticeable. The Standards and publications available give only certain limitations for feel system characteristics, but there is no guidance as far as their optimum values is concerned. The selection of the optimum feel system characteristics presents certain difficulties due to their and control sensitivity (control gradient) interdependence. Thus, the selection of manipulator feel system characteristics is usually made empirically on the basis of pilot comments and experience in using manipulators of the similar type.

For a long time pilot models are effectively used for objective assessment of aircraft handling qualities. Since 70-90, when fly-by-wire control systems and new non-traditional manipulators (such as sidestick, for example) were introduced, pilot models have being developed in view of detailed description of pilot model at frequencies typical of neuromuscular system. Despite of the quite a number of studies (McRuer and Magdaleno, 1971, Hess, 1990, Mitchell et al., 1992, 1994, van Paassen, 1990, van Paassen et al., 2004, etc.), no one of publications scrutinized pilot models from point of view of feel system characteristics optimality.

The present work is to determine effects of control manipulator feel system characteristics on pilot model and its components, such as limb-manipulator and neuromuscular systems, in order to find any objective indicators of feel system characteristics optimality.

2. RELEVANT WORKS

Difficulties in selection of optimum feel system characteristics are due to the fact that they depend on control sensitivity, which, in turn, depends on aircraft dynamics. This complex interdependence is referred to by many experts (Johnston and Aponso, 1988, Lee et al., 2004, Zaichik et al., 2004). That is why, maybe, publications available on the feel system characteristics limit to differences between pilot-aircraft transfer functions for force and position sensing force-feel systems (Hess, 1990), and limitations for certain feel system characteristics (Mitchell et al., 1992, 1994, Watson and Schroeder, 1990, etc.).

Theoretical approach developed in late 90s (Rodchenko et al., 1998) is the only comprehensive tool which reveals physics of complex interdependence of feel system characteristics and control sensitivity, and allows estimation of their optimum. But the approach is based on subjective pilot ratings, and no objective data or criteria have been found so far to confirm the optimality of the selected manipulator feel system characteristics.

Piloting accuracy is often tried as an objective parameter to assess aircraft handling qualities. The data in Figure 1 shows that piloting accuracy does not change within the very wide range of force gradient and damping variation and, thus, it

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can not be used for objective criterion to assess feel system characteristics optimality.

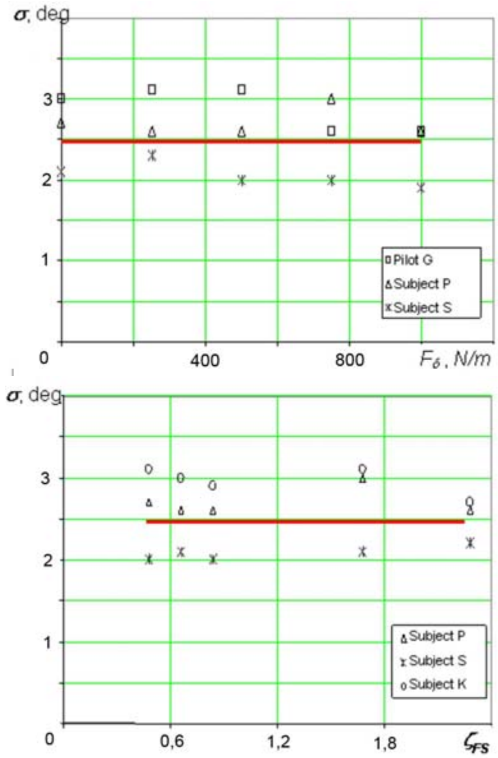

Fig. 1. Tracking accuracy as a function of manipulator force gradient (F_δ) and damping ratio (ζ_{FS}).

It is natural to suppose that the effect of manipulator feel system characteristics can be analyzed with the help of neuromuscular system study. The neuromuscular system functioning demonstrates itself by pilot model transfer function peaking at frequencies 16-18 rad/s. Pilot models of different complexity have been proposed to describe neuromuscular system functioning (Hess, 1990, van Paassen, 1990, van Paassen et al, 2004). But neither simple, nor complex models can explain yet feel system characteristics optimality.

Figure 2 shows that pilot model transfer function changes with gain (i.e. with control sensitivity). It is seen that as aircraft gain increases by factor K, a pilot changes his gain correspondingly by factor $1/K$ in order to support pilot-aircraft system cutoff frequency constant.

At the same time, pilot model transfer function is not sensitive to feel system characteristics, which is confirmed by recent experiments conducted by authors (Zaichik et al., 2013). Figures 3 and 4 shows Bode plots of pilot model transfer functions measured in roll tracking task for a central stick and sidestick. It is seen that effect of gradient is negligible along all range of frequencies, though some tendencies can be traced at low frequencies. As forces gradient is smaller than optimum (for a sidestick and center stick, it is within 4-6 N/cm), the pilot manipulator deflections become more extensive, and the describing function gain increases a little. At high frequencies, effect of force gradient is irregular.

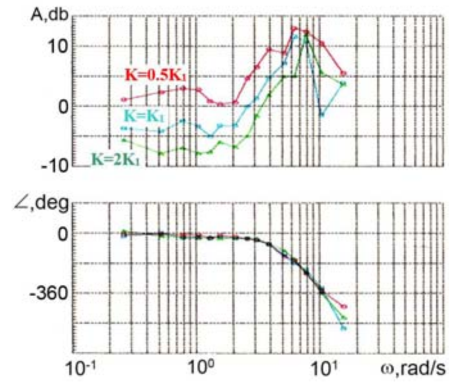

Fig. 2. Pilot model transfer functions for different aircraft gain.

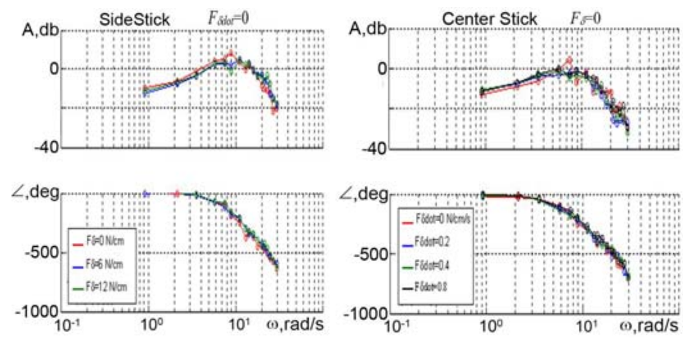

Fig. 3. Effect of force gradient on the pilot model transfer functions for a central stick and sidestick.

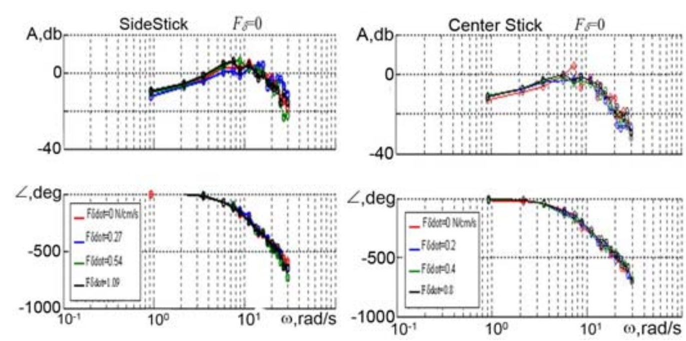

Fig. 4. Effect of manipulator damping on the pilot model transfer functions for a central stick and sidestick.

Figure 4 shows that the inceptor damping does not affect pilot transfer function for rather wide range of the damping variation (from 0 up to very heavy damping). The point is that at frequencies typical of active control, the introduction of additional damping does not lead to any noticeable increase of inceptor forces felt by a pilot, and, thus, does not affect handling qualities pilot ratings.

To confirm the last statement, Figure 5 and 6 show data received for the wheel in the course of earlier study (Zaichik et al., 2013). Figure 5 shows HQ ratings for two test pilots as a function of damping ratio (the values varied from ζ=0.3 up to 1.2). It is seen that despite of the fact the damping varied in a large range, the pilot ratings did not noticeably change. Figure 6 shows the percentage of forces due to damping