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Measuring simulation fidelity through an adaptive pilot model

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Abstract

The paper presents a new approach to the quantification of simulation fidelity based on an analysis of pilot guidance strategy. The manoeuvre guidance portrait is conceived as the solution to a low-order equivalent system and to properly allow for pilot adaptation to changing cues and task demands, the model parameters are allowed to vary. Thus the concept of the Adaptive Pilot Model (APM) is proposed and developed. The theoretical foundation to the concept is developed using the familiar spatial variables in flight control, such as distance and speed. Motion is then transformed into temporal variables and drawing on the theory of $\tau(t)$-coupling from visual flow theory ($\tau(t)$ is the instantaneous time to contact) the APM model is transformed into a much simpler algebraic relationship when the pilot maintains constant $\dot{\tau}$ during a deceleration. If we make assumptions about the separation of guidance and stabilisation control strategy, pilot guidance feedback gains are then closely related to the frequency and damping of the APM structure. Results are presented from the analysis of simulation trials with pilots flying an acceleration-deceleration manoeuvre that show strong correlation with the $\tau(t)$-based guidance strategy. The interpretation of the theory in terms of simulation fidelity criteria is discussed.

Keywords: Flight simulation; Pilot modelling; Simulator validation

1. Introduction

The level of fidelity of Flight Simulators, or, more generally Synthetic Training Devices (STD), determines their fitness for purpose and is quantified in documents like JAR-STD-1H [3] in terms of performance criteria for the individual components, e.g. the motion/visual/sound systems, the mathematical model. Component fidelity is important but the standards also require piloted assessment of the integrated system with typical mission sorties flown covering the training aspects for which the system will be used. Subjective opinion here is important too because it reflects the value that an experienced pilot places on the level of realism. Quantifying overall simulation fidelity is more difficult however, but is equally important because, arguably, component or sub-system fidelity can only be properly related to fitness for purpose if connected by measure to the whole. Attempts to quantify overall simulation fidelity within the framework of handling qualities engineering have been presented in a number of forms in recent years. Hess and colleagues [7,8,19] have developed an approach based on pilot-aircraft modelling and introduced the handling qualities sensitivity function as the basis of a quality metric. McCallum et al. propose the use of the ADS-33 [2] performance standards for deriving metrics [12]. Within the JSHIP project, Advani and Wilkinson [1], and Roscoe and Thompson [18] present an approach using comparative measures of performance and control activity, correlated with handling qualities ratings given for the same tasks flown in simulation and flight. In all these approaches, the philosophy has been to develop a rational and systematic approach to identifying differences between tasks performed in simulation and flight, hence directing attention to simulation deficiencies. While Ref. [3] is directed at the training community, fidelity criteria are equally applicable to the use of simulation in design, research and development. In these areas, flight simulation can be a primary source of data from which knowledge is

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Nomenclature

g	gravitational constant
K_R, K_X	pilot gain relating pitch attitude command to range error
$K_{\dot{R}}, K_{\dot{X}}$	pilot gain relating pitch attitude command to range rate
k	τ coupling parameter
R	range
R_c	range command ($= X_0$)
s	Laplace transform variable
T	manoeuvre time
X	distance to go
$\dot{X}$	rate of change of distance to go (velocity)
$\ddot{X}$	acceleration
X_u	surge damping derivative
$Y_{A\theta}$	transfer function relating pitch attitude to range
Y_{PR}	transfer function relating range error to pitch attitude command
$Y_{P\theta}$	transfer function relating attitude command to pitch attitude
θ	aircraft pitch attitude
θ_c	aircraft pitch attitude command
τ_θ	pitch response time constant (inverse of pitch bandwidth ω_θ)
ζ_R, ζ_X	closed loop damping
ω_R, ω_X	closed loop frequency
$\tau(t)$	time to contact
τ_g	τ guide
$\dot{\tau}$	rate of change of τ with time

derived, decisions are made and significant resources committed.

This paper presents the initial developments in an approach for quantifying overall simulation fidelity based on an analysis of pilot visual guidance strategy, identifying the control loops utilised, levels of abruptness and the cues available to support anticipation. The premise is that if the control strategy adopted to perform the same flying task is 'equivalent' in flight and simulation, then the fidelity is good and the training device fit for purpose. The meaning of equivalent is developed in terms of what we describe as the *Adaptive Pilot Model* (APM) concept, whereby the combined pilot and aircraft is modelled and comparisons made of model parameters identified from the same curve fitting process applied to data from flight and simulation tests. As with previous studies, the research is thus concerned with approximations for describing the behaviour of the combined pilot-aircraft system. However, in the present work, it is assumed that the pilot adapts control strategy during the manoeuvre, with the adaptation reflected in the changing model parameters. Thus the changing pilot gains relating to velocity and distance control, for example, are tracked through the manoeuvre. The concept is then extended under the premise that motion control by the pilot follows temporal rather than spatial guidance principles, as described in Ref. [15]. The results presented in Ref. [15] indicate that pilots strictly have no need for velocity or distance information, per se, when manoeuvring close to a surface. Instead, they use information about time to close on surfaces, $\tau(t)$, to make judgements about relative motion and control requirements. The APM structure and temporal guidance approach is illustrated with reference to an acceleration-deceleration manoeuvre. Results are shown for several test cases from flight simulation.

The theoretical foundations of the Adaptive Pilot Model concept as applied to the manoeuvres under investigation are developed, followed by a re-interpretation of flight control in terms of $\tau(t)$ and its derivative. Results are presented from flight simulation tests, illustrating the utility of the approach. The topic of simulation fidelity is then discussed in terms of open and closed loop criteria, and future directions of the present research activity are outlined, followed by some Concluding remarks.

2. The adaptive pilot model concept

2.1. Theoretical formulation

A pilot's task can be divided into three functions, with descending orders of timescale magnitude; navigation (O(100 sec)), guidance (O(10 sec)) and stabilisation (O(1 sec)). In this paper we are essentially interested in the guidance task, the manoeuvring around and over obstacles and coming to a stop in particular areas. We make the assumption that the navigation function is too long term, and the stabilisation function too short term to cause interference with the guidance strategy. These assumptions will not always be true, of course. The overlap of control demands for stabilisation and guidance is known to be a source of pilot-induced-oscillations [14] and the spare capacity for guidance can reduce significantly when the pilot loses his or her way. Within the framework of the stated assumptions, the guidance task involves control of the velocity and position of the aircraft, relative to the Earth, in the inertial frame.

The concept of the adaptive pilot model for guidance can be traced back to the work of Heffley [5,6], who examined stopping manoeuvres using low-order equivalent systems to represent the coupled aircraft-pilot system. Considering the hover-to-hover re-positioning, acceleration-deceleration manoeuvre, aircraft motion can be displayed on a so-called phase-plane portrait of velocity against range. Fig. 1 shows examples of different cases to highlight the generality of this concept. Results are taken from flight tests conducted on the Bo105 and Bell 412 helicopters, together with simu-