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 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 stop) the ADP model is shown to simplify 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 simply related to frequency and damping of the ADP 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.

Symbols

g	gravitational constant
K_R	pilot gain relating pitch attitude command to range error
$K_{\dot{R}}$	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)
$\zeta_{R(X)}$	closed loop damping
$\omega_{R(X)}$	closed loop frequency
$\tau(t)$	time to contact
τ_g , τ_x	τ guide, τ motion
$\dot{\tau}$	rate of change of τ with time

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 (Ref 1) 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 (e.g. Refs 2-4) 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 (Ref 5) performance standards for deriving metrics (Ref 6). Within the JSHIP project, Wilkinson and Advani (Ref 7), and Roscoe and Thompson (Ref 8) 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 1 is directed at the training community, fidelity criteria are equally applicable to simulation in design, research and development. In these areas, flight simulation can be a primary source of data from which knowledge is derived, decisions are made and significant resources committed.

This paper presents a developing 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* (ADP) 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 9. The results presented in Ref 9 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 ADP 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 τ and its derivative. Results are presented from flight simulation tests, illustrating the utility of the approach. The topic of simulation fidelity is then discussed and future directions of the present research activity are outlined, followed by some Concluding remarks.

The Adaptive Pilot Model Concept

Theoretical Formulation

A pilot's task can be divided into three functions, with descending orders of timescale magnitude; navigation (*O(100 seconds)*), guidance (*O(10 seconds)*) and stabilisation (*O(1 second)).* 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 slow, and the stabilisation function too fast 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 (Ref 10) 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 (Refs 11, 12), 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 simulation cases with Lynx, Bo105 and UH-60. The relatively simple and similar portraits for these manoeuvres hide a complex pilot control strategy and associated aircraft attitude response, and widely varying aircraft dynamics across the low speed range.

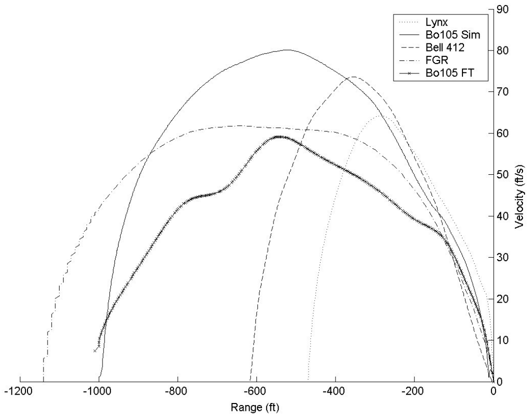

Fig 1 Phase-Plane Portraits for Accel-Decel Manoeuvres

Heffley recognised that the form of the portraits in Fig 1 resemble the free response of a second order (spring-mass-damper) system released from an initial displaced condition. If the distance travelled by the aircraft is the range R, the distance to stop X and the total range R_c, as shown in Fig 2, then the closed-loop pilot-aircraft system can be presented in the transfer function form given in Fig 3.

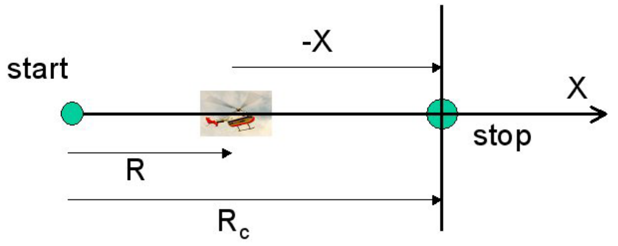

Fig 2 Kinematics of the Acceleration-deceleration Manoeuvre

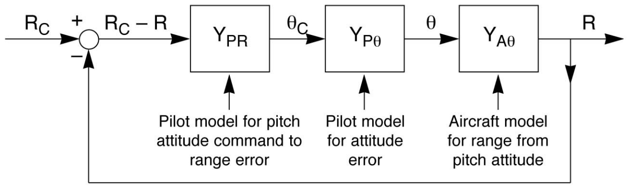

Fig 3 Closed-loop Control of Aircraft Range

The pilot initiates the manoeuvre under the command R_c and concludes when the error (R_c-R) is reduced to zero. In Fig 3, θ_c is the commanded pitch attitude and θ the actual pitch attitude. The linear transfer function formulation is used for convenience in this description. It is recognised that the non-linear behaviour of the ADP, i.e. pilot model parameters varying with the motion, means that the linearity assumption breaks down. A non-linear time-domain formulation is used at this stage. The pilot transfer function Y_{PR} is assumed to take the form of a lead, with proportional and differential gains (K_R and $K_{\dot{R}}$) on range error and velocity;

$$Y_{PR} = K_R + K_{\dot{R}} s \tag{1}$$

The transfer function $Y_{P\theta}$ represents the pilot-aircraft, short-term pitch dynamics (stabilisation function) and is assumed to take the form of a first order lag with time constant τ_θ (bandwidth ω_θ), written as;

$$Y_{P\theta} = \frac{1}{1+\tau_\theta s} \tag{2}$$

The aircraft transfer function between range response and pitch attitude is approximated in first order form, including the drag derivative X_u;

$$Y_{A\theta} = \frac{-g}{s(s-X_u)} \tag{3}$$

The open loop transfer function between range error and range is then given by;

$$\begin{aligned} Y &= Y_{PR}\, Y_{P\theta}\, Y_{A\theta} = \\ &= -\frac{g}{s(s-X_u)}\frac{1}{(1+\tau_\theta s)}\left(K_R + K_{\dot{R}} s\right) \end{aligned} \tag{4}$$

The dynamics of the free response of the system to a displaced initial range are given by the equation 1+Y=0, or;

$$\frac{s^3}{\omega_\theta} + \left(1 - \frac{X_u}{\omega_\theta}\right)s^2 + \left(gK_{\dot{R}} - X_u\right)s + gK_R = 0 \tag{5}$$

Applying the further approximation that the closed loop attitude dynamics are much faster than the translational dynamics, and that $\omega_\theta >> -X_u$, the system reduces to 2^{nd} order form,

$$s^2 + 2\varsigma_R \omega_R s + \omega_R^{\ 2} = 0 \tag{6}$$

where the pilot gains are related to the natural frequency ω_R and damping ratio ζ_R by the expressions,

$$K_{\dot{R}} \approx \frac{2\zeta_R \omega_R}{g} \qquad K_R \approx \frac{\omega_R^{\ 2}}{g} \tag{7}$$

In the continuing analysis and discussion it is convenient and appropriate to transform the system into an equivalent initial value problem in the time domain, in terms of the distance to go in the manoeuvre, X (see Fig 2), rather than range R; thus we write,

$$\begin{aligned} &\frac{d^2X}{dt^2} + 2\zeta_X \omega_X \frac{dX}{dt} + \omega_X^{\ 2} X = 0, \\ &X_0(0) = -R_C \end{aligned} \tag{8}$$

Initially the aircraft is at rest in the hover, the command R_c is transformed into an initial condition, causing the pilot to command a pitch down attitude through K_X and so the acceleration phase of the manoeuvre begins. At this stage the control inputs are almost open loop so we might expect the gain to be relatively low. As the velocity builds up so the motion is damped through $K_{\dot{X}}$, an effect that we might expect to strengthen for the deceleration phase. Intuitively, we might also expect the pilot gain to increase as the stopping point is approached and loop closure tightened. In Ref 11, Heffley estimates constant values of $K_{\dot{R}}$ of 4 deg/kt and K_R of 1deg/ft for a UH-1H performing a quick-stop from 40kts in flight; peak nose up attitude during the aggressive deceleration was 40deg. These gains correspond to a constant natural frequency and damping ratio of 0.8 rad/sec and 0.7 respectively. Heffley goes on to argue the need for a pitch attitude bandwidth (ω_θ) of about 2.5 rad/sec to ensure that pilots utilising this level of aggressiveness can do so within Level 1 handling qualities (i.e. a large separation of guidance and stabilisation frequencies). This work was conducted prior to the publication of ADS-33 (Ref 13) that eventually set the pitch bandwidth requirement for hover/low-speed tasks at 2 rad/sec. By inferring stabilisation requirements from guidance requirements, in a sense we are able to set a protective margin against adverse aircraft-pilot couplings. It is clearly important that a flight simulator gives the pilot a realistic sensation, providing realistic cues, in this regard, otherwise aircraft designs or training outputs could be flawed. In the next section we continue the theoretical developments, re-casting the guidance cues from spatial to temporal forms.

τ-Coupling Guidance Strategy

The re-formulation of the motion model in terms of distance to go in eqn (8) facilitates an examination of visual guidance strategy through the direct visual perception parameters in the optical flow. Gibson (Ref 14) introduced the concept of optical flow as the way in which patterns change or points move on the surfaces over and around which motion is occurring. The perception system that picks up and organises these 'cues' has evolved to be robust and efficient in the animal world as a key function in the survival game. Likewise, an important requirement for pilots to maintain safe flight is that they are able to predict the future trajectory of their aircraft far enough ahead that they can stop, turn or climb to avoid a hazard; the pilot needs to be able to see optical flow well into the future. In Ref 15, Lee suggested that an animal's ability to determine the time to close on an object does not depend on knowledge of the size of the object, the closing speed or distance. Lee hypothesised that the 'looming' of the object, or the ratio of its size to the rate of growth of its image on the retina, is actually the fundamental optical variable used in nature. As for a bird approaching a branch, for the pilot in the accel-decel manoeuvre the looming is defined in terms of the instantaneous time to contact τ(t), as;

$$\tau(t) = \frac{X}{\dot{X}} \tag{9}$$

The time to contact information can readily be scaled in terms of eye-heights, and using a combination of surface and object *τ(t)'s*, afford animals (and pilots) with knowledge of the height of the surrounding terrain with respect to themselves. In Ref 9, *τ(t)* theory was applied to helicopter manoeuvring to gain a better understanding of guidance strategies. Initially the deceleration phase of the manoeuvre was examined in isolation to model the guidance strategy during stopping and, in particular, to establish if the strategy aligned with evidence in nature that birds come to a stop while maintaining a constant rate of change of *τ(t)* (Ref 16). The rate of change of *τ(t)* with time can be obtained by differentiating eqn (9),

$$\dot{\tau} = 1 - \frac{X \ddot{X}}{\dot{X}^2} \tag{10}$$

With X<0 (see Fig 2), then $\dot{\tau}$ >1 corresponds to accelerating flight, $\dot{\tau}$ = 1 corresponds to constant velocity and $\dot{\tau}$ < 1 corresponds to a deceleration. It can be shown (Ref 9) that the aircraft will come to a hard stop (deceleration maximum late in the manoeuvre) if $\dot{\tau}$ >0.5 or a soft stop (deceleration maximum early in manoeuvre) if $\dot{\tau}$ <0.5. A constant deceleration throughout the manoeuvre implies that $\dot{\tau}$ =0.5. The extent to which pilots hold a constant $\dot{\tau}$ during the stopping phase of the accel-decel can be established by computing the correlation between *τ(t)* and time. Fig 4, taken from Ref 9, shows results for Lynx across the whole manoeuvre; a peak pitch attitude of about 15deg occurred when the velocity had reduced to about 20kts in the deceleration.

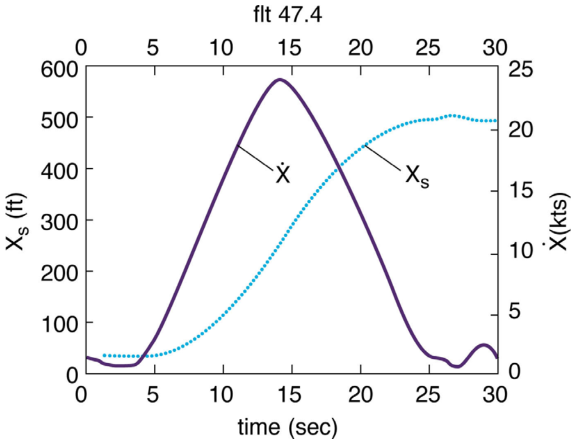

Fig 4 Velocity and Range for Lynx flying an Accel-Decel (Ref 9)

The corresponding correlation fit is shown in Fig 5 for the final 11 seconds of the manoeuvre. For consistency between runs, the initial and final 10% of the data were removed from the fit (i.e. the manoeuvre was taken to end when the velocity reached 10% of the peak value). Over this range, the correlation coefficient is remarkably high at R^2 = 0.983 and the fit coefficient or $\dot{\tau}$ = 0.505. The pilot is tracking $\dot{\tau}$ very closely.

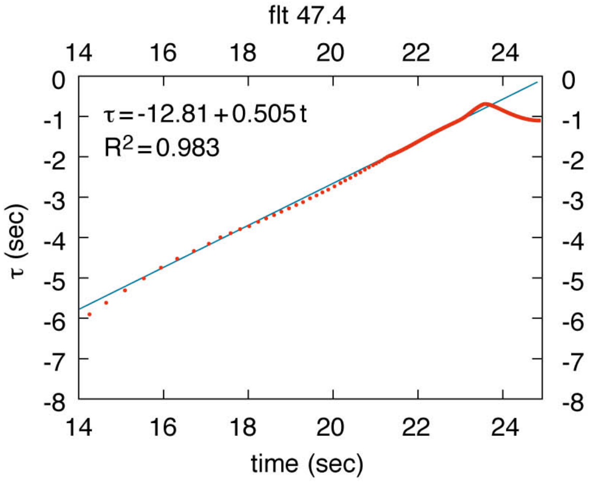

Fig 5 Correlation of τ(t) with time for the stopping phase in Fig 4

In terms of the adaptive pilot model, the constant $\dot{\tau}$ guidance strategy has a particular significance.

Multiplying eqn (8) by $\dfrac{X}{\dot{X}^2}$, we can write,

$$\frac{X\ddot{X}}{\dot{X}^2}=1-\dot{\tau}=-2\zeta_X(\omega_X\tau)-(\omega_X\tau)^2 \quad (11)$$

With $\dot{\tau}$ constant, eqn (11) implies that the product

$$\omega_X\tau=const. \quad (12)$$

or, that ω_X and hence the pilot gain are inversely proportional to the time to stop. For the limiting case when $\dot{\tau}$ =0.5 (constant deceleration), real solutions are possible when $\zeta\geq 0.707$. When $\zeta=0.707$, we have,

$$\omega_X\tau=0.707 \quad (13)$$

so that when τ is 4 seconds (see Fig 5), ω_X = 0.18rad/sec and when τ is 1 second, ω_X = 0.707 rad/sec. These values correspond to pilot feedback gains of,

τ = 4 seconds,

$$K_X=0.06\deg/ft, K_{\dot{X}}=0.8\deg/kt$$

τ = 1 second,

$$K_X=0.9\deg/ft, K_{\dot{X}}=3.0\deg/kt$$

The values close to the stopping point are similar to those derived in Ref 11, but there a constant pilot strategy was assumed throughout the manoeuvre. Very close to the stopping point, the value of pilot gain cannot increase indefinitely, and a different guidance strategy must switch in. This region is outside the scope of the present analysis.

Further evidence that pilots adopt $\dot{\tau}$-based guidance strategies can be found in Ref 17. Flight tests were conducted at NASA to derive the optimum deceleration profile for helicopters approaching a landing pad. The research was conducted to establish the preferred guidance strategy adopted by pilots for use in director-based displays. From a wide range of tests conducted using 3 different helicopters, the deceleration profile was found to fit the curve based on the function,

$$\ddot{X}=\frac{k\dot{X}^2}{X^n} \quad (14)$$

Re-arranging terms and substituting for $\dot{\tau}$, this relationship can be written in the form,

$$\dot{\tau}=1-kX^{1-n} \quad (15)$$

where k and n are parameters that vary as a function of initial range and airspeed. With n = 1, a constant $\dot{\tau}$ strategy is adopted, but the data from Ref 17 predicted n to vary between 1.2 and 1.7. Clearly pilots do not always favour the $\dot{\tau}$ constant strategy and there is a suggestion that, during decelerating, descending approaches, the need for coordination between horizontal and vertical motion leads the pilot to adopt a more complex $\dot{\tau}$-based strategy.

In the development of general τ-theory (Ref 18), Lee has recognised this in the concept of τ-coupling. Quoting from Ref 9, …"*General tau theory posits that the closure of any type of gap, using any form of sensory input, is guided by sensing and constantly adjusting the tau of the gap. The theory shows, for example, that information solely about* $\dot{\tau}_x$ *is sufficient to enable the gap x to be closed in a controlled manner, as when making a gentle landing*." In the case of the accel-decel manoeuvre the pilot effectively initiates a mental model of the manoeuvre, described as an intrinsic τ-guide, and locks onto this throughout the manoeuvre. The constant $\dot{\tau}$ strategy can be shown to result from the coupling with a constant velocity τ-guide. The whole accel-decel cannot be flown like this however, but it can be shown that the necessary guiding motion is a constant acceleration. The constant acceleration guide has the form (Ref 9),

$$\tau_g = \frac{1}{2}\left(t - \frac{T^2}{t}\right) \qquad (16)$$

and

$$\dot{\tau}_g = \frac{1}{2}\left(1 + \left(\frac{T}{t}\right)^2\right) \qquad (17)$$

Taking the same manoeuvre shown in Fig 4 and assuming the relationship, $\tau = k\,\tau_g$, the fit with the constant-acceleration guide is shown in Fig 6.

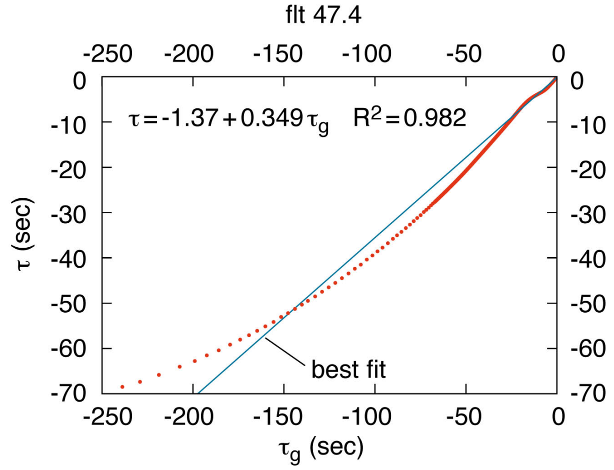

Fig 6 Correlation of τ(t) with τ_g for the whole accel-decel in Fig 4

The fit is now good over the whole manoeuvre and, during the final stages, the constant velocity and acceleration guides converge.

The quadratic relationship in eqn (11) holds for the whole manoeuvre, with the general solution given by,

$$\omega_X \tau = -\zeta \pm \sqrt{\zeta^2 - (1 - \dot{\tau})} \qquad (18)$$

In the very initial stages of the manoeuvre, when t<<T, eqn (18) can be written in the approximate form,

$$\omega_X \approx -\frac{\sqrt{\dot{\tau}}}{\tau} \approx \frac{1}{T}\sqrt{\frac{2}{k}} \qquad (19)$$

According to the ADP model, the initial closed loop natural frequency is therefore inversely proportional to the manoeuvre time (one might intuitively expect this) scaled by the coupling coefficient k. For the case shown in Fig 6, according to eqn (19), the initial value of ω_X is then about 0.13 rad/sec, or very similar to the value predicted by the constant $\dot{\tau}$ guidance model at the beginning of the deceleration phase (0.12=0.707/τ). The results suggest that the pilot may adopt a strategy that keeps the positional gain constant (frequency remains constant) during the acceleration phase and then stiffens to a maximum as the hover is approached. We now examine the applicability of the ADP model approach in a preliminary analysis of simulation test data.

Preliminary Results from Flight Simulation Tests

Fig 7 shows the first results of the ADP model applied to Lynx piloted simulation data shown in Fig 4. The Figure shows the velocity profile and the estimated dampings and frequencies using 2 second data windows and a least squares fit process. The longitudinal cyclic history is also shown. A fairly constant frequency is accompanied by an increasing damping during the acceleration phase. At the beginning of the deceleration phase, the frequency has settled to about 0.2rad/sec (cf with 0.13rad/sec from eqn (9)), with the damping staying constant at about 0.75 until the final 50ft of the manoeuvre. The results are therefore reasonably consistent with the simple theoretical predictions.

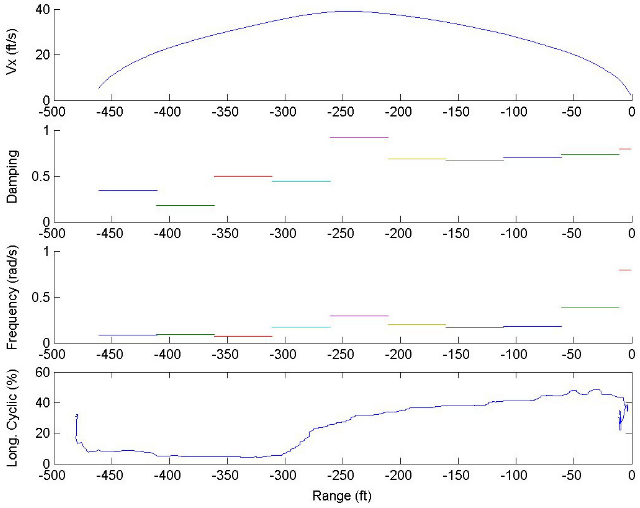

Fig 7 Adaptive Pilot Model applied to Lynx flying accel-decel manoeuvre

Piloted tests have also been flown on the Liverpool flight simulator, shown in Fig 8. This facility is described in some detail in Ref 19 and includes 6 axes of motion, 5 outside-world visual channels and an electric control loader system – all programmable. The FLIGHTLAB modelling and simulation package is used to build, analyse and run models.

Fig 8 The Liverpool Flight Simulator

As part of the ADP research, tests have been flown with Bo105 and the FLIGHTLAB generic rotorcraft (UH-60 like) models. The ADP results for the UH-60 are presented in Fig 9 and Fig 10, the latter showing the correlation of motion $\tau_X(t)$ with guide $\tau_g(t)$ over the whole accel-decel.

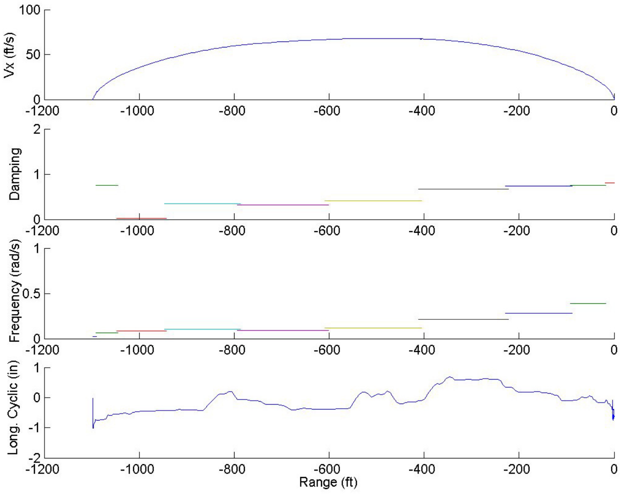

Fig 9 Adaptive Pilot Model applied to UH-60 flying accel-decel manoeuvre

The accel-decel is of longer duration than the Lynx test, with a distance of 1100ft covered and a maximum velocity of about 60ft/sec reached and held approximately constant for a significant portion of the manoeuvre. Similar frequency and damping variations, compared with the Lynx results, are predicted across the manoeuvre. The time to stop correlation with the constant acceleration guide is again strong with a coupling coefficient of about 0.46.

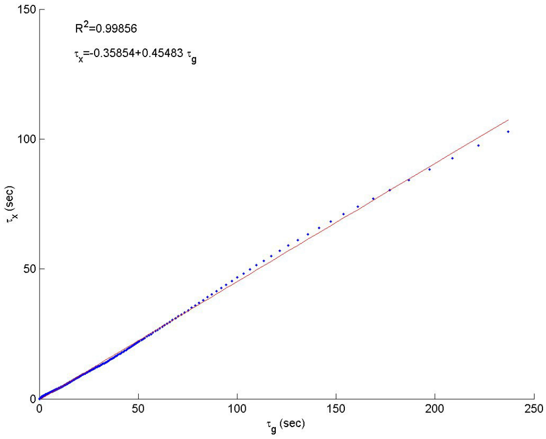

Fig 10 Correlation of τ_X and constant acceleration τ_g for UH-60

The equivalent Bo105 results are shown in Figures 11 and 12. The frequency and hence positional gain rises as the manoeuvre is completed but here the damping increases above critical, corresponding to the pilot increasing the velocity feedback as the stopping point is reached.

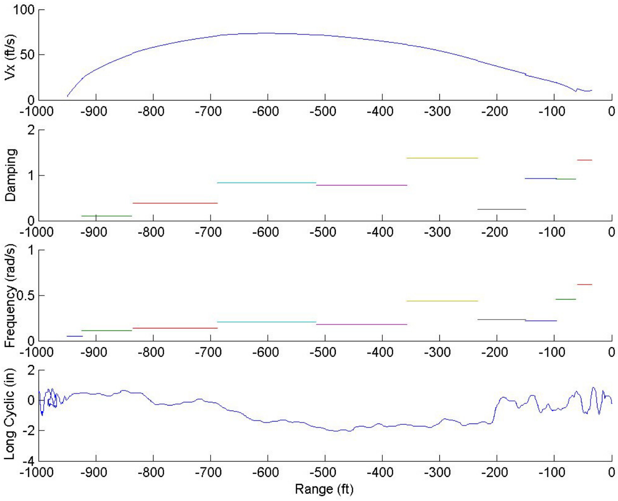

Fig 11 Adaptive Pilot Model applied to Bo-15 flying accel-decel manoeuvre

The time to stop correlation is again high but a close examination of Fig 12 reveals that the fit close to the stopping point is poor.

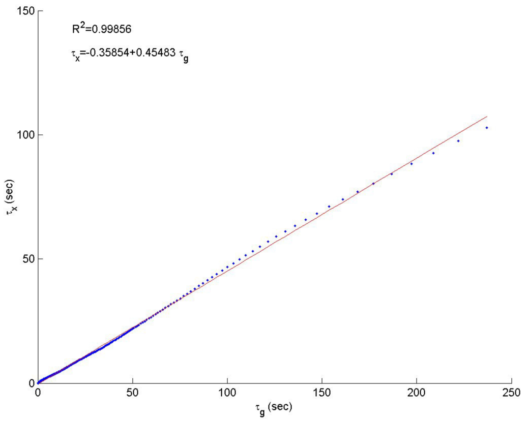

Fig 12 Correlation of τ_X and constant acceleration τ_g for Bo-105

The results shown in Figs 9-12 are preliminary and any observations made or conclusions drawn are reported as tentative at the time of writing. Several other test runs have been analysed that suggest variations in pilot gains and guidance strategy throughout the manoeuvre that do not fully accord with the simple ADP model, and a more thorough investigation is underway to shed light on the pilot adaptation process as well as the parameter estimation process adopted.

Simulation Fidelity – a Discussion

The value of the ADP model approach in simulation fidelity assessment will be measured by the sensitivity of the estimated closed-loop system parameters to changes in pilot guidance strategy, brought about by changes in simulation component characteristics, e.g. model accuracy or the quality of the simulation visual and vestibular motion cues. This sensitivity must also correlate with pilot opinion of course. In the continuing investigations these aspects will be explored both in the context of changes to the simulation environment and in the context of direct comparisons between simulation and flight. It will be important to calibrate the model for changes in task demands on the one hand, for example the level of pilot aggressiveness used, and also for known changes in simulation component fidelity, for example in the details of the rotor modelling or the visual cues. To be robust, the method should feature systematic changes in model parameters (and hence the guidance strategy adopted) derived from systematic changes in the simulation fidelity. The interpretation of motion control in terms of $\tau(t)$ in this paper has also enabled a simpler, more direct modelling scheme – mirroring the direct process of visual perception present in the natural world. Modelling through $\tau(t)$ coupling appears to offer the potential for achieving 'optimum' harmony between the different motion cueing systems and this aspect will also be explored in the continuing research.

The question of how accurate a mathematical model needs to be to satisfy different simulation requirements is to some extent still an open question. In a series of 'Action Groups' GARTEUR has addressed this topic over the years with a particular emphasis on modelling for performance and handling qualities prediction (e.g. Ref 20). Ref 1 is now a published standard but there has been no published analysis, to the authors' knowledge, of the relationship between the performance measures and fidelity. Such an activity will form part of the work of the current GARTEUR Action Group HC-AG12, and the research reported in this paper forms an element of that work.

Our research continues with a focus on flight-simulation comparisons and the development of useful fidelity metrics from the ADP model structure. The FLIGHTLAB Bo105 developed at Liverpool is being compared with flight test data provided by the DLR Braunschweig. A baseline FLIGHTLAB model is close to release at the time of writing and a typical comparison, showing the pitch response to longitudinal cyclic doublet in hover, is shown in Fig 13.

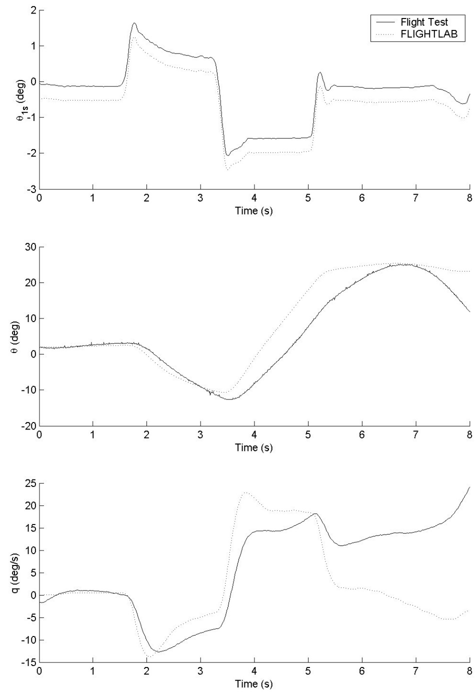

Fig 13 Response to Longitudinal Cyclic in Hover; comparison of Flight Test and FLIGHTLAB simulation – Bo105

The pitch response match falls outside the ±10% error band required in Ref 1 but this is not untypical of the blade-element modelling standard used. The usual process in the continuing refinement of fidelity is to include control gearing and other non-physical parametric changes to improve the match. The refinement process is often very time consuming and there are no formal best practice guides available. On a more positive note, the better the physical model, the less non-physical corrections will be required and the pursuit of this level of modelling fidelity has to be a continuing priority in the simulation/aeromechanics communities.

Concluding Remarks

This paper has outlined the theoretical foundations for the adaptive pilot model concept for flight motion guidance and presented the first results from application to data from piloted simulation trials. It has been shown that a second order system approximation of the ADP can be used when the timescales for flight guidance and stabilisation are well separated. The system frequency and damping ratio are then directly related to pilot gains in the feedback control strategy. Transforming the system from spatial to temporal variables results in a first order differential equation in the time to stop, $\tau(t)$. It then follows that when the pilot follows a constant $\dot{\tau}$ guidance strategy during the deceleration phase of an accel-decel manoeuvre, the natural frequency (and pilot positional gain) varies inversely with $\tau(t)$, a strategy which clearly breaks down very close to the stopping position. A more general guidance approach to the whole accel-decel manoeuvre is described where the pilot locks onto a motion guide moving with constant acceleration. Initial results derived from piloted simulation data confirm the principles of motion described by the ADP model structure. The ADP model is being developed in the current research at Liverpool for application to simulation fidelity assessment. Criteria will be developed based on the sensitivity of the pilot gains used in closed loop tasks to simulation fidelity. The continuing work will exam the utility of the ADP model in detecting fidelity changes from visual and vestibular motion cues and also simulation model fidelity based on a Bo105 helicopter, with test data provided by the DLR Braunschweig.

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