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SIMULATION OF PILOT CONTROL ACTIVITY FOR THE PREDICTION OF WORKLOAD RATINGS IN HELICOPTER/SHIP OPERATIONS.[1]

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Abstract

The dynamic behaviour of aerospace systems is conventionally assessed through a combination of open loop simulation to quantify the characteristics of the response to prescribed control inputs and man-in-the-loop simulation to evaluate the closed loop pilot-vehicle dynamics. The use of a piloted flight simulation facility with moving base and high quality visual scene generation can be expensive and time consuming. It is an area where representation of the pilot as a dynamic control element can supplement the man-in-the-loop for handling qualities and workload investigations and offer several important benefits. The paper describes a generic pilot model called SyCoS [1,2], (Synthesis through Constrained Simulation), able to fly a helicopter along a prescribed flight path. It is based on the crossover model of McRuer and Krendel [3] where the actions of the operator (here, the pilot) correct errors between the actual outputs and the desired references. Examples of the application of the SyCoS pilot to a FLIGHTLAB implementation of a Lynx helicopter carrying out basic manoeuvres such as side-step and accel / decel are presented. The paper then describes the application of the SyCoS pilot model to a simulated deck landing task as performed for establishing limits for helicopter/ship operations. Comparison with data from piloted simulation conducted on the Advanced Flight Simulation facility at DERA Bedford confirms that the SyCoS pilot can successfully emulate this task and replicate key aspects of the pilot strategy in guidance and response to environmental disturbances. Some enhancements to the basic SyCoS model have been incorporated to achieve a more realistic representation of the hysteresis and threshold effects that can be identified in the data from piloted simulation. This authentic simulation of the control activity allows the application of predictive techniques for quantifying pilot workload. The techniques, based on adaptive wavelet analysis, were developed and validated by DERA and GCU in an extensive programme of collaborative research [4,5] and more recently have been applied to helicopter / ship operations. Predictions of the workload experienced by pilots during helicopter/ship operations is the primary aim of this work and the paper concludes by presenting some preliminary results.

1 Background

During operations of a helicopter from the flightdeck of a ship, the pilot has to maintain safe flight whilst dealing with the effects of the invisible airwake surrounding the ship and the motion of the flightdeck as it reacts to the sea state. The ability to complete these tasks will depend on the characteristics of both aircraft and ship as well as wind conditions, sea state and available visual cues.

Before any new helicopter / ship combination can be cleared for operations a set of limits must be established, defining the envelope over which safe launch and recoveries can take place. Currently, the so called Ship Helicopter Operating Limits (SHOL) are determined by conducting flight tests at sea using the aircraft and ship combination for which an envelope is required. There are several problems with this process not least of which is the monetary cost of conducting such trials. However, in addition the trials require a service aircraft and ship to be removed from other duties for the duration of the trial, typically two weeks - and there is no guarantee that the desired combinations of wind and sea state will be obtained during this time. Although in some cases a SHOL may be derived from the limits of other similar aircraft /

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ship combinations already in use, for unfamiliar combinations the SHOL can only be defined for those conditions actually tested. Where the test matrix has not been achieved during the trial, a SHOL will be issued which may be unnecessarily limited due to lack of test data.

Over the last few years dynamic models of aircraft, ship and environment have been developed at DERA Bedford for the purpose of providing a real time simulation capability for use in defining Ship Helicopter Operating Guidelines (SHOG). It is intended that SHOGs be calculated prior to sea trials in order to identify potential problems early on and target the flight test matrix accordingly. Although further development work is still required, the results from using the simulator have been promising, as described by Fitzjohn and Turner[6]. The simulator offers a number of benefits to the SHOL capture process in that an evaluation can be made for new combinations more cheaply and the test matrix can always be executed in full and in any order. The simulator would also allow for repeat test points to be flown under identical conditions with a different pilot.

The subject of this paper is a further enhancement to the modelling and simulation of this scenario allowing estimation of SHOLs using desktop simulation that uses a computer model of the human pilot. The use of models in this way not only offers further cost savings when used in conjunction with piloted simulation, but also provides a quick and efficient method for assessing new systems or modifications to existing systems. Examples would include evaluation of helicopters fitted with novel control systems or ships with enhanced design features to make the airwake more amenable to helicopter operations. The proposed methods could potentially be used at the design stage of either ship or aircraft or as a tool for operational analysis providing estimates of shipborne helicopter availability.

In the following, Section 2 presents a description of the pilot model, Synthesis through Constrained Simulation (SyCoS), and details its implementation in the FLIGHTLAB modelling environment. In Section 3 examples are shown giving SyCoS predictions of control activity for basic sidestep and accel / decel manoeuvres as well as comparisons with control activity from piloted simulation for a traverse manoeuvre over the flightdeck of a ship in the presence of ship airwake and turbulence. Sections 4 and 5 describe a Wavelet Analysis technique for estimating pilot workload from control time histories. The method has been used to predict workload ratings for a set of control time history data from piloted simulation and compared with pilot subjective ratings from the same trials. Sections 6 and 7 present the conclusions from the work and describe future activities.

2 The SyCoS Pilot Model

The SyCoS model has been developed to emulate pilot control activity during manoeuvring flight in a more authentic manner than the ‘perfect pilot’ of inverse simulation [7]. In particular, it is required to capture the corrective responses initiated by a pilot when a departure from the requirements of the manoeuvre is perceived. This departure may be a result of external disturbances such as atmospheric turbulence, a localised wind variation or a reappraisal of the effect of previous control activity on the vehicle’s flight path. McRuer and Krendel in the development of their crossover model showed that an operator adapts to the system that he/she is operating in such a way as to achieve an overall transfer function between the perceived error and the system output that is independent of the system being controlled. This invariant transfer function is a combination of a gain, a pure delay (reaction time), and an integration. These properties are clearly in evidence in the basic SyCoS structure shown in Figure 1 where the main components are the system being piloted – in this case a state of the art flight dynamics helicopter model - and a pilot model consisting of (i) an inverse of the system and (ii) a crossover element incorporating a gain, delay and an integration. The cancelling effect of the combination of a system and its inverse makes it clear that between the error and the system output there is simply the required crossover transfer function.

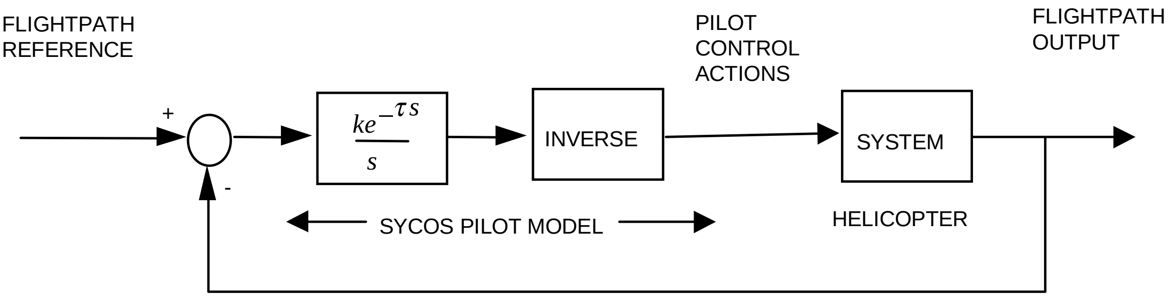


Figure 1; The basic SyCoS structure

Within the pilot model, the inverse component of the pilot model represents the pilot's adaptation to the aircraft's dynamics: later we shall pay particular attention to the implementation of this system inverse since, potentially, it is computationally complex. Validation of the crossover model by McRuer and Krendel was largely confined to single input / single output systems but in this work the principle has been extended to a multi-axis system with four axes of control and, correspondingly, four references. The assumption inherent in this extension is that the pilot learns to adapt fully to a multi-axis system including the coordination required to compensate for any cross axis coupling. With a multi-axis system, the gain, K, and delay, $e^{-\tau s}$, are matrices - which for this work are diagonal with each axis treated identically.

It is possible, of course, to employ the system inverse to control the helicopter directly – as in inverse simulation [7] - but such use of the inverse would not satisfy the requirements of a corrective model and would therefore respond to external disturbances in an unrealistic manner. It is also worth emphasising that, although Figure 1 represents a control structure, its purpose is to emulate a pilot's control strategy and its development and interpretation should be addressed with that aim in mind. So a 'better' model in this context does not necessarily mean improved closeness between output and reference but a control activity which is closer to that of a human pilot. Specifically, we wish features in the control activity to be sufficiently similar to those of a human pilot as to allow realistic workload ratings to be derived from them. This aspect will be addressed later, in the section dealing with prediction of workload in simulated helicopter / ship operations.

2.1 Practical Implementation

The implementation of the SyCoS pilot is greatly facilitated by appreciating that the inversion required need not be exact. First, with a corrective structure any discrepancies that appear on the output as a result of any inaccuracy tend to be cancelled out by pilot action. In addition, since the inverse represents the pilot adaptation to the system under control there is every reason to omit high frequency dynamics beyond the range at which a pilot would normally try to compensate. The task is therefore one of inverting a simple model based on the pilot's perception of the vehicle dynamics. In the current work the vehicle model is linearised about a typical operating point, such as an initial trim, and the order reduced to obtain a 6 d.o.f. model with a state vector consisting of body referenced velocity components, body referenced angular velocity components and the three Euler angles: ($u,v,w, p, q, r, \phi, \theta, \psi$), in the usual notation. The inversion of a linear model with respect to a given output vector, state feedback z, is a standard procedure and follows the approach for nonlinear systems [8,9]. Briefly, the procedure is as follows. For the linear system

$$\dot{x} = Ax + Bu \qquad (1)$$

with output equation

$$z = Cx \qquad (2)$$

it is possible, by successive differentiation of the output equation to derive an equation of the form:

$$\bar{z} = \bar{C}x + \bar{D}u \qquad (3)$$

with $\det(\overline{D}) \neq 0$, where $\bar{z}$ consists of components of $\dot{z}$ or higher derivatives. If the derivatives of z are replaced by the corresponding derivatives of the reference, z_{ref}, then the application of the feedback

$$u = \overline{D}^{-1}(\bar{z}_{ref} - \overline{C}x) \qquad (4)$$

will generate an output that follows the reference exactly so that u calculated in this way is the inverse of the required output $\bar{z}_{ref}$. In fact, the output $\bar{z}$ follows $\bar{z}_{ref}$ exactly - which is not quite the same as z following z_{ref}. This aspect is discussed in the next section.

This whole inversion process is quite simple and in practice is achieved in no more than six matrix statements. The general case can not be written down explicitly however because the detail depends on the particular form of the output matrix C, which defines the quantities which are to follow the applied references. The approximate inverse is incorporated into the SyCoS system as shown in Figure 2. *L(s)* in this figure represents the operations / differentiations needed to create $\bar{z}$ from z.

2.2 Reference Definition

Manoeuvres are specified by four references which allow the four controls positions to be calculated. Usually the required flight path is specified by defining the earth referenced position of the vehicle centre of mass as a function of time. In addition it is usual to specify the heading angle or angle of sideslip also as a function of time to make up the four reference values defining uniquely the four control positions. In fact, the CG positions cannot be used directly. The differentiations in the inverse method reflect the fact that the controls act directly to produce accelerations and it is these quantities which need to be specified as references - and this may not be sufficient if the task is to follow a position reference. To overcome this difficulty it is possible to redefine the state feedback to allow positional references - essentially equivalent to converting the positional error into an acceleration error which will eliminate the positional error. In this work feedback corresponding to a second order filter:

$$F(s) = \frac{\omega_n{}^2}{s^2 + 2\varsigma\omega_n s + \omega_n{}^2} \qquad (5)$$

on each component of the position error vector is employed and an appropriate choice of filter parameters is chosen to give a reasonable time response and stability of the combined system. SyCoS with the modified feedback is shown in Figure 3. The matrices *H* and *G*, involving ζ and ω_n, are diagonal stiffness and damping matrices respectively and again each axis can be tuned individually. This form is termed the CTM - the Compensatory Tracking Model. It allows the use of the primitive variables: that is, CG coordinates and heading angle, as references but the penalty is the inclusion of a tracking filter. In pilot modelling terms the CTM emulates the process whereby the pilot detects an error in position and estimates the accelerations/control activity necessary to compensate for it. The attenuation by the low-pass filter is not deleterious since the pilot would not react to high frequency error signals.

2.3 Stability Considerations

The combined SyCoS helicopter system has simple modal properties. First there is the set of free modes associated with the controls-fixed full helicopter model being piloted. These are conveniently evaluated in the trim at which the system is linearised before model reduction to build the inverse. SyCoS does not augment stability and so the free modes are still present in the total system.

The inverse model in isolation has 9 states and the nature of its modes for a conventional helicopter are well known. Since it is constrained to follow four references there are four modes with zero eigenvalues. There is another zero associated with the heading angle and the remaining eigenvalues are associated with two types of oscillatory behaviour: in pitch and in roll both with the CG stationary. These modes are the zero dynamics of the inverse system [8] and are usually close to neutral stability. In the closed loop SyCoS system the four zero eigenvalues associated with the four constraints are influenced by the crossover element and are instead convergent modes

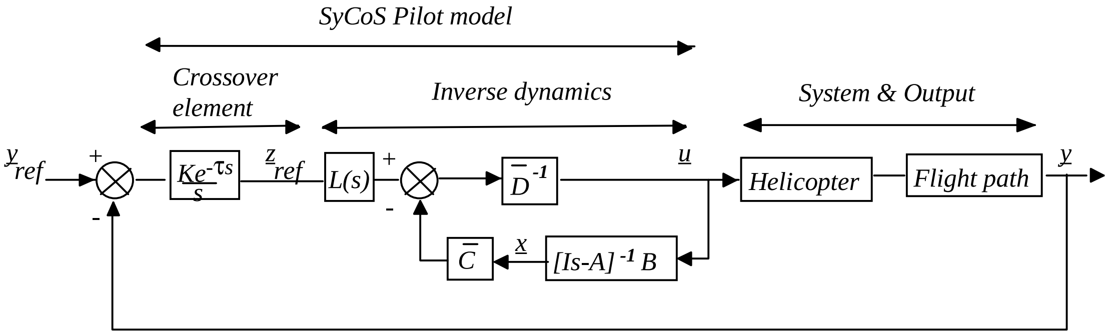


Figure 2; Implementation of SyCoS pilot model with approximate linear inverse

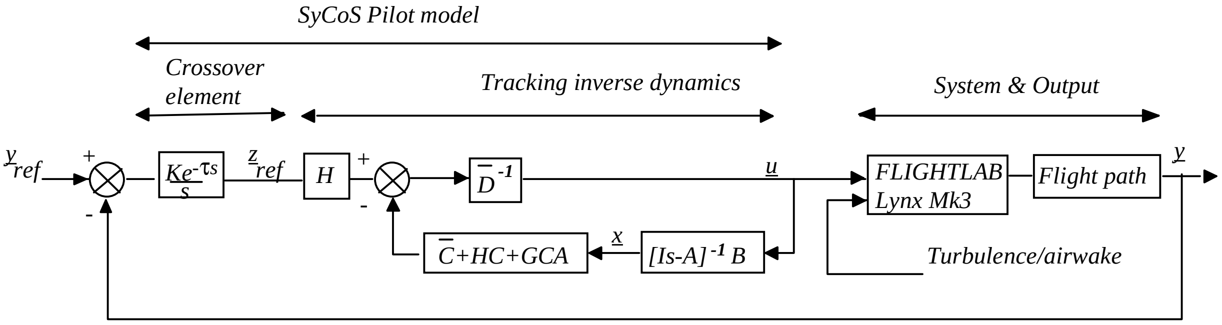


Figure 3; Implementation of CTM SyCoS pilot

with eigenvalues numerically equal to the four diagonal elements of the gain matrix *K*. The CTM with its second order filter element modifies this situation and the eigenvalues estimated from the characteristic equation obtained by ignoring the small delay τ:

$$s(s^2 + 2\varsigma\omega_n + \omega_n{}^2) + kw_n{}^2 = 0 \qquad (6)$$

for each individual axis combination of k,ω_n and ζ. It is a simple matter to show that stability is maintained provided $k<2\omega_n\,\zeta$.

In summary, the stability properties depend on (i) those of the uncontrolled vehicle, (ii) an appropriate choice of the parameters for the gain and filter and (iii) stable zero dynamics in the model inverse - this latter is usually the case for conventional helicopters but it is not obvious at the outset

3 Examples

The use of SyCoS for piloting a helicopter through basic manoeuvres is illustrated by Figures 4 and 5 which depict control responses for low aggression sidestep and accel / decel manoeuvres respectively from handling qualities criteria ADS-33[10] .

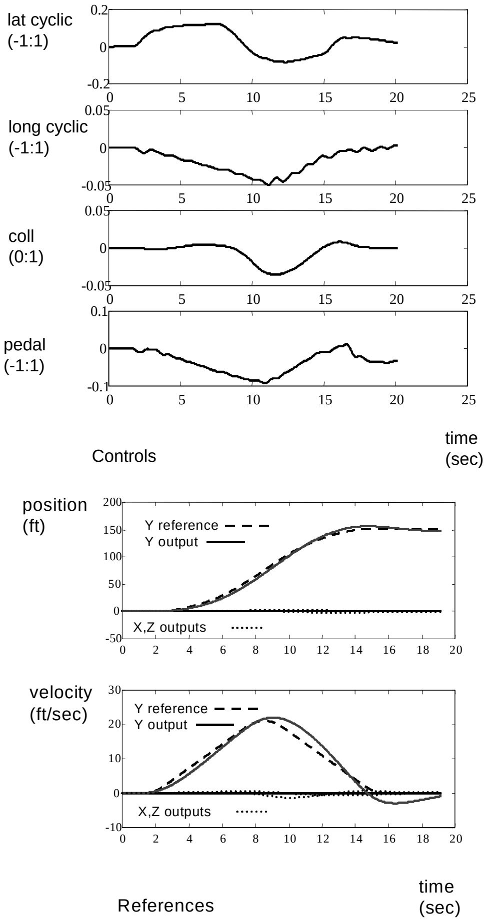
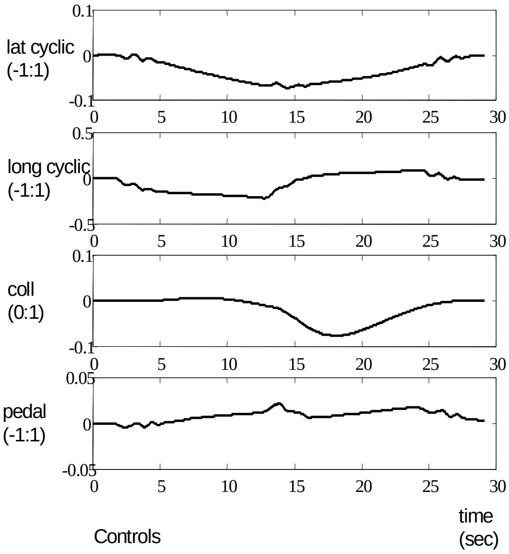
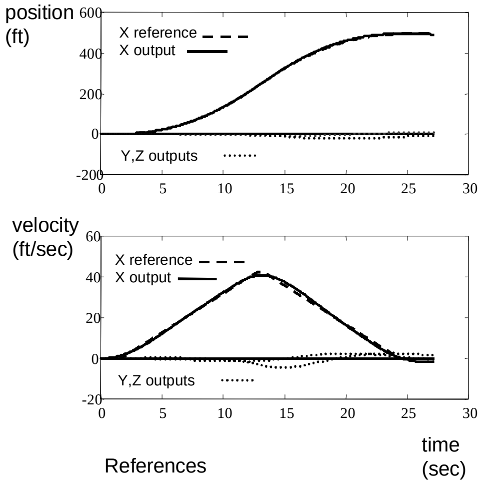


Figure 4; SyCoS outputs for a sidestep manoeuvre



Controls



References

Figure 5; SyCoS outputs for an accel / decel manoeuvre

The model helicopter is a fully nonlinear Advanced Rotorcraft Technology FLIGHTLAB implementation of a GKN Westlands Lynx Mk 3 and includes individual aeroelastic blades, AFCS, actuators etc. FLIGHTLAB enables trim, linearisation and model reduction to be readily accomplished for the generation of the inverse component of SyCoS. The flight paths are generated by piecewise polynomials as commonly used in inverse simulation. The four controls together with a comparison of the reference and achieved positions and velocities are shown in Figures 4 and 5. It is clear that the manoeuvres are carried out adequately and that all controls are active in piloting the helicopter through these simple repositioning manoeuvres.

3.1 Enhancements and Limitations

Since the zero dynamics modes are easily excited by flight-path discontinuities or other disturbances it may be necessary to take steps, such as by slightly modifying the output matrix, C, to stabilise them - or almost equivalently - by adding stabilising state feedback. Inspection of control responses from human pilots suggests that they have a strategy for preventing these oscillations from building up, but as task workload takes precedence, their appearance can be observed. As yet, it has not been possible to include a convincing representation of this observed strategy in SyCoS.

Comparisons of control records from human pilots with those from SyCoS have revealed some characteristic discrepancies. There are two of particular note: (i) the collective control from the AFS has a stepped appearance while that from SyCoS is smooth and (ii) there is much more cyclic activity in the piloted simulations than in the SyCoS emulations. These discrepancies motivated the inclusion of non linear elements in the SyCoS model and after some experimentation their most effective location is illustrated in Figure 6; a hysteresis element is attached to the control leading to the helicopter and a dead zone is placed across the error prior to its processing by the crossover elements. The latter represents a threshold of the perception of departure from the reference values while the former gives stiction on control levers. Hysteresis set on the collective lever alone replicates the ‘stepped’ nature of the pilot activity as shown in Figure 7 which is a comparison of control activity produced by SyCoS and piloted simulation during a deck traverse in the presence of turbulence and airwake. The agreement in the collective and pedal activity is encouraging, but there is less success in reproducing the high level of cyclic activity which, as will be shown later, is a major factor in the prediction of workload. It is believed that the excitation of high levels of cyclic activity is related in some way to the phenomenon of zero dynamics.

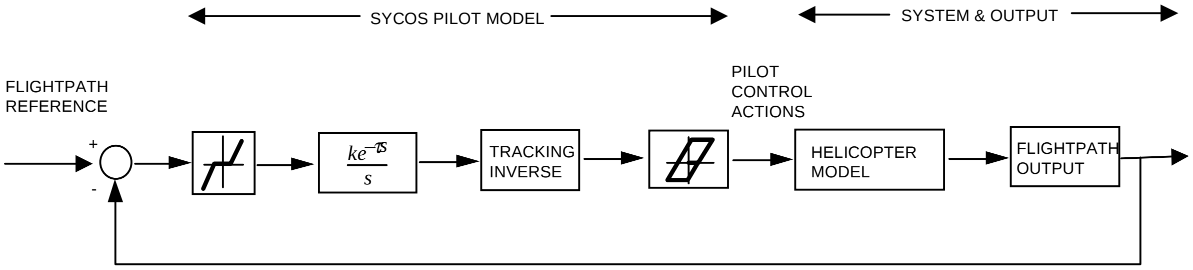


Figure 6; The SyCoS structure with nonlinear elements

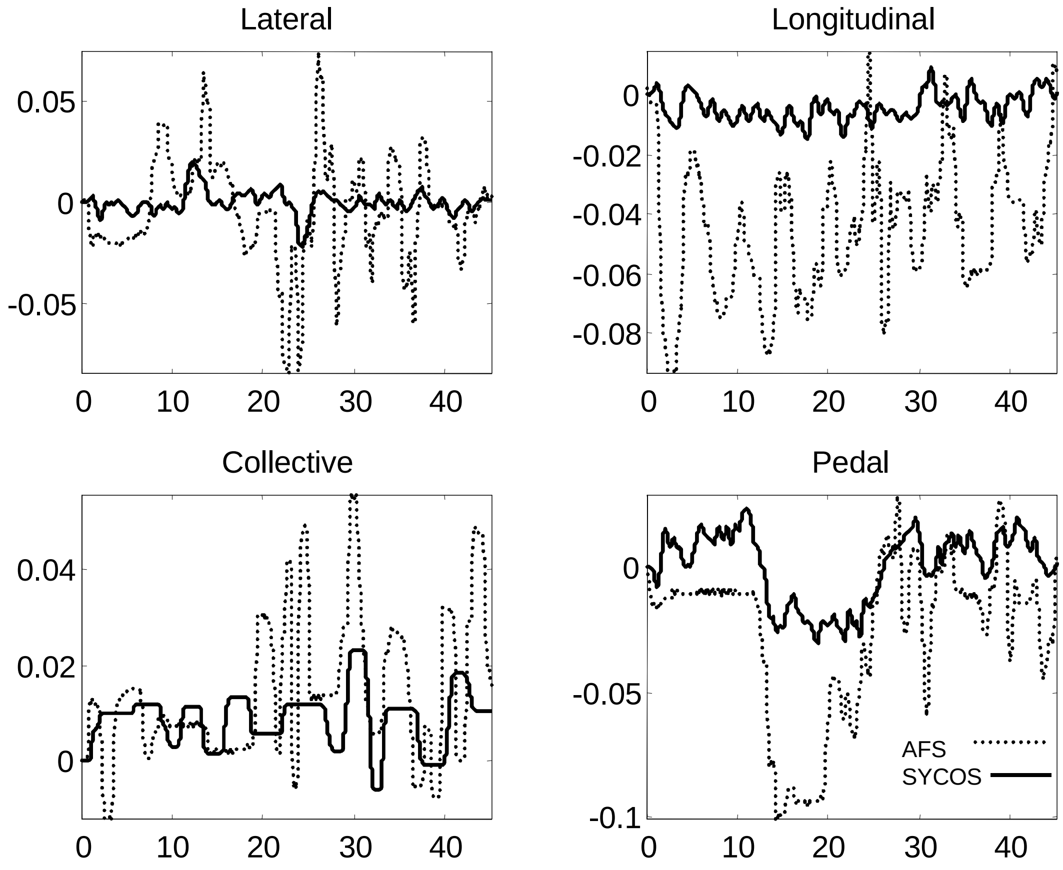


Figure 7; Comparison of control responses from SyCoS and piloted simulation

A recognised paradigm for a model of a pilot carrying out a complex task is a hierarchy of declarative, procedural and reflexive actions. The high level declarative actions are related to goal planning and are largely mission oriented, delivering a sequence of objectives to the lower levels of the hierarchy. Procedural actions are those which are automatic, trained, open loop, actions such as those which initiate a planned manoeuvre or an avoidance of a threat. The lowest level, reflexive, actions relate to automatic corrective actions to eliminate some perceived error between actual and desired output. The SyCoS model, being corrective by design, clearly sits at the lower level of the hierarchy. The higher level functions are emulated by designing reference profiles - that is flight paths - which realistically capture those functions. For example, the goal of carrying out a sidestep manoeuvre with increased aggression invokes the trained response to provide the requisite attack, or initial acceleration, into the manoeuvre. For a SyCoS piloted simulation of the manoeuvre the flightpath supplied as reference must incorporate a corresponding initial acceleration. Therefore at the present time, it is the flight path design which must carry goal planning and procedural actions into the SyCoS framework.

4 Prediction of Workload

As has been seen in the previous sections, the SyCoS model can provide estimates of the control activity required to conduct a recovery to a ship and this could be applied for any wind condition and sea state where models are available. In order to define a SHOL it is necessary to identify those combinations of wind condition and sea state which are not safe for helicopter operations. The limit is normally defined by either insufficient torque margin, insufficient pedal margin or excessive pilot workload. If it is assumed that the control activity has been predicted reliably, then the detection of torque and pedal limits becomes trivial. However, the identification of cases where excessive workload was required demands some additional analysis.

The method used for this purpose is Wavelet Analysis and aims to take as input the time histories of control activity and produce an estimate of the overall workload contained within the signals.

It is important to note that workload has many facets which combine to give the overall effort required to perform a particular task. These may include mental evaluation of the situation possibly under pressure, scanning for and interpretation of visual cues and the physical effort required not only to move the cockpit inceptors but also to endure the vehicle accelerations. Wavelet Analysis as applied here can only detect those aspects of workload which manifest themselves in the control activity. This will inevitably lead to poor estimates being obtained from the method in some cases, where judgements are needed to estimate the importance of other aspects. Furthermore, a control signal containing significant activity does not necessarily indicate a high workload. A complex manoeuvre, such as an ADS33 style Mission Task Element, may require a significant number of sizeable inputs across all axes but if the pilot has flown many repetitions, they may become second nature and will not incur a large workload penalty. It is however the amount of pilot compensation which will be the main aspect of workload likely to be detectable in the control time histories. Such compensation may be due to the need to overcome deviations from the intended flightpath or the effects of external disturbances. Usually associated with these control inputs will be a package of mental and physical activity which will therefore be accounted for Wavelet Analysis of the control activity.

The following sections present an overview of the method and examples of its application first to piloted simulation data and then to synthetic control responses from SyCoS. Full details of the analysis technique are intended for publication in the near future.

5 Wavelet Analysis

As described by Padfield *et al* [5] the analysis of a control signal using wavelets involves decomposition of the signal into a collection of discrete control actions of a particular form given by the shape of the analysing wavelet. The analysing wavelet can be varied according to the nature of the signal being considered but for these studies an optimum wavelet was used throughout and is shown in Figure 8. The wavelet is dominated by a sharp ramp followed by a slowly decaying tail. The decomposition of the signal comprises a number of wavelets each of which is characterised by its amplitude (height of ramp), scale (duration of ramp in time) and position in the signal. For each wavelet an "attack parameter" is calculated from these parameters which relates to the aggressiveness with which the input was made and is akin to the quickness parameter used extensively in ADS-33[10] for defining handling qualities requirements. To estimate workload from the wavelet decomposition a two phased approach has been developed. Firstly, a statistical analysis is made of the attack parameters from the entire signal. Secondly, the clustering of wavelets within segments of the control signal is considered using a variable shape wavelet analysis. The analysis is repeated for each control channel before combining estimates to give an overall workload rating.

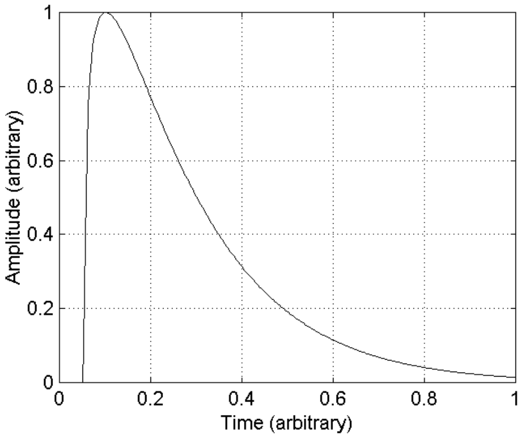


Figure 8; Profile of a single wavelet

5.1 Attack Chart Analysis

The attack parameter gives an indication of the aggressiveness of a particular discrete input and is inversely proportional to the scale of the wavelet ramp. It has been identified by Charlton et al [4] that in order to analyse workload it is necessary to consider a wavelet feature belonging to one of four bands, depending on its attack parameter and relating to whether the function of the input was to provide flightpath guidance or stabilise the vehicle. At the largest scales the attack parameter is small and the wavelet is grouped in the guidance band. As the attack parameter increases there are three stabilisation bands containing wavelets of decreasing scale i.e. stabilisation band 1 contains inputs of a larger scale and smaller attack parameter than bands 2 and 3. The number and amplitude of wavelets in each band are analysed and plotted on an exceedance chart as shown in Figure 9 – showing an example of an analysed lateral cyclic input recorded in the Advanced Flight Simulator at DERA Bedford. Each line on the plot represents an attack band and gives for a certain input amplitude (plotted on the horizontal axis) the number of wavelets whose amplitude exceeds this value. The guidance band is shown by the triangle symbol and stabilisation bands 1 to 3 by the square, circle and cross respectively.

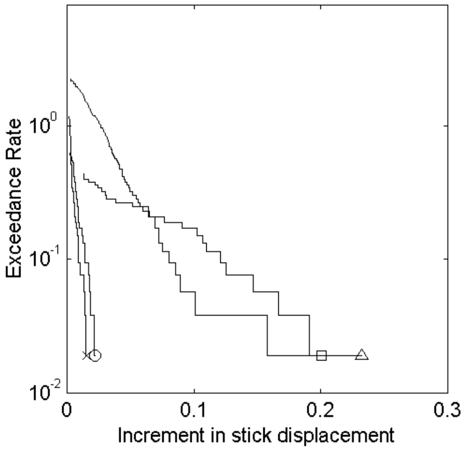


Figure 9; Exceedance chart for lateral cyclic

The position and shape of the exceedance lines are analysed and compared to a set criteria to quantify their contribution to the overall workload. The criteria are developed from a set of training data – in this case using control time histories from piloted simulation where a pilot rating of workload was also available. Although all the exceedance lines will feature in the workload estimate, in general, the stabilisation band 1 is the most significant as this contains information relating to the large amplitude pilot compensation inputs.

5.2 Variable Shape Wavelet Analysis

By itself the attack chart analysis is not sufficient to estimate workload in all cases, as it does not consider the clustering of wavelet features within the control signal. The second phase of the workload prediction is to search for sequences of wavelets which are indicative of pilot over-controlling or, in extreme circumstances pilot induced oscillations. These so called variable shape wavelets are characterised by the number of cycles they contain, the total energy of the sequence and the attack parameter of the constituent wavelets. An example of an identified variable shape wavelet is shown in Figure 10 using an extract from a lateral cyclic signal. As for the attack chart analysis, a set of criteria have been derived from piloted simulation data to determine how each variable shape wavelet contributes to the overall workload. Once contributions from all control channels have been calculated they are added to the workload estimate from the attack chart analysis to give an overall workload rating for the task.

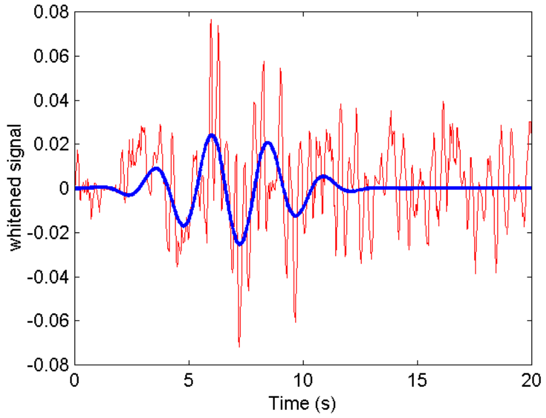


Figure 10; Example of a variable shape wavelet

5.3 Analysis of piloted simulation data

A set of eighteen deck landing manoeuvres from piloted simulation have been used to illustrate the performance of the method. The wavelet workload prediction has been scaled to give values equivalent to Cooper-Harper Handling Qualities Ratings (HQR), as this was the form in which pilot subjective ratings were available. Although the Cooper-Harper scale is a handling qualities scale which takes into account not only workload but also system deficiencies and task performance, a strong correlation between HQR and workload is normally expected. The comparison of pilot HQR and predicted workload is shown in Figure 11 in which it is seen that the majority of estimates are within one HQR point, indicating that the method has correctly distinguished between high and low workload cases.

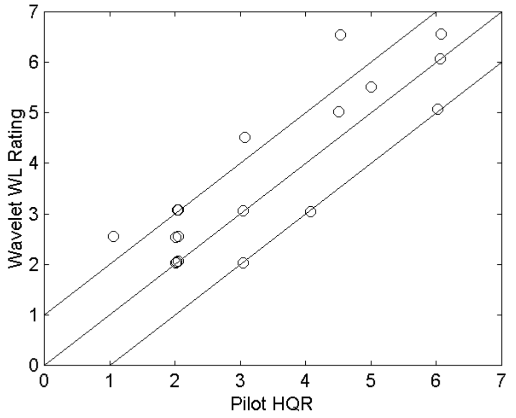


Figure 11; Comparison of workload predictions with pilot subjective ratings

5.4 Analysis of SyCoS data

For the current work it is intended to apply wavelet analysis to synthesised control activity derived using SyCoS. To define criteria for use with these data requires an appropriate set of training data for which a knowledge of the true workload is available. Such a data set is not readily available as there is no pilot involved to give a rating. Therefore, it is intended that SyCoS be used to replicate the control actions from piloted simulation data and the workload assumed to be given by the associated pilot subjective rating. Reliable criteria will only be obtained if control activity is reproduced with good accuracy and so this task has not been completed whilst the SyCoS pilot model is still under development. The lateral and longitudinal cyclic activities in particular need further enhancement. Once the best configuration of the pilot model has been finalised and suitable rating criteria developed a viable method will be in place to make workload predictions for any test conditions for which the models are available. Although work so far has concentrated on replicating pilot HQRs, in its final state the algorithm need only place the workload on a two point scale - acceptable or unacceptable.

Some analysis has already been conducted on SyCoS data although no workload rating is available for the reasons stated above. Two such cases are shown below to illustrate the behaviour of the exceedance lines when workload increases. Both cases are for a traverse of a Lynx over the flightdeck of a Type 23 Frigate with the wind coming from a direction of 45 degrees to starboard at 30 kn. In the first case the model only injects vertical gusts whereas in the second, both vertical and horizontal gusts are encountered. Figures 12 and 13 show the control time histories for all four channels for the first and second cases respectively. The amplitudes are on a scale of 0 to 1 for collective and –1 to 1 for all other controls. It is seen that collective and pedal activities are roughly equivalent but the lateral and longitudinal cyclic activities both increase for the second case when horizontal gusts are introduced. The exceedance charts are shown in Figures 14 and 15 for lateral cyclic (upper plot) and longitudinal cyclic (lower plot) where the characteristic shift to the right is clearly visible for the guidance and first stabilisation bands. The equivalent cases in the flight simulator produced an increase in HQR from 2 to 4.5. Further data like these must be explored to reliably define new criteria for workload prediction.

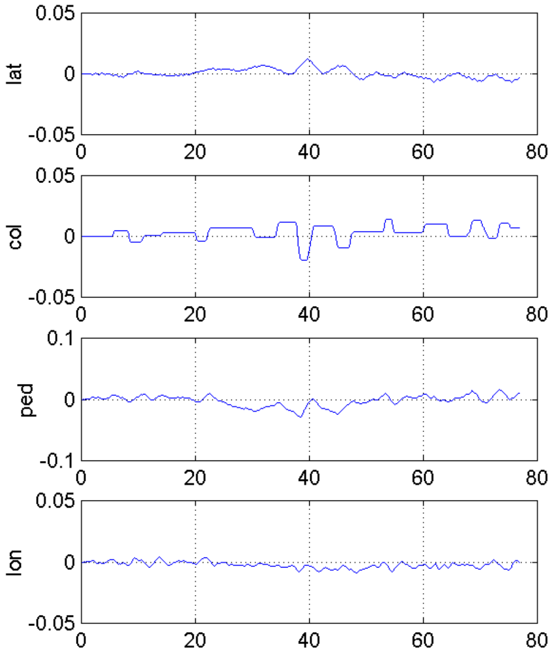


Figure 12; Control responses for case 1 (vertical gusts only)

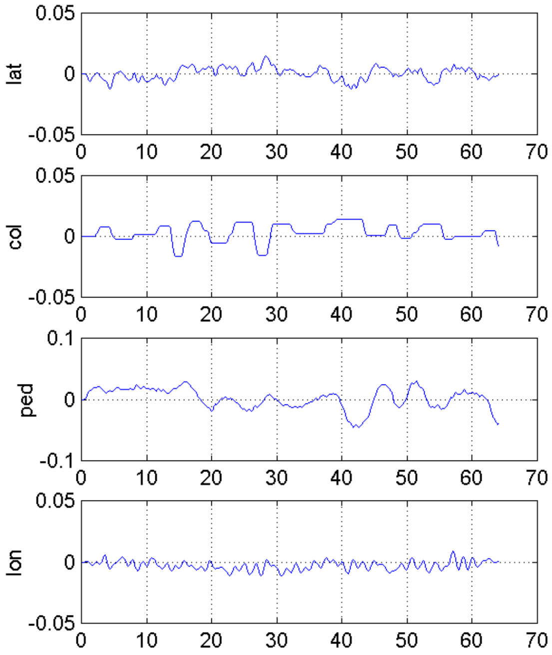


Figure 13; Control responses for case 2 (horizontal gusts included)

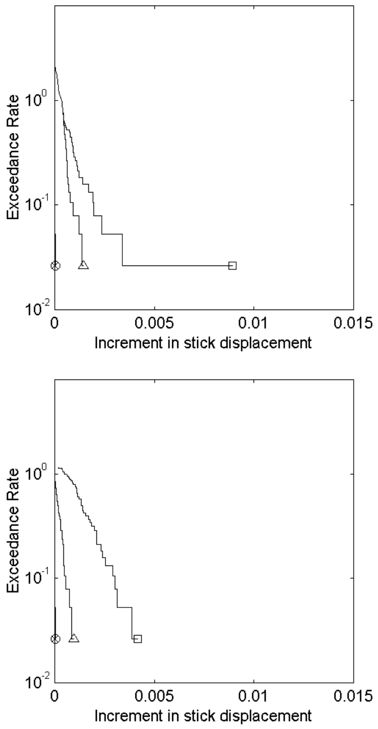


Figure 14; Exceedance charts for case 1 (vertical gusts only)

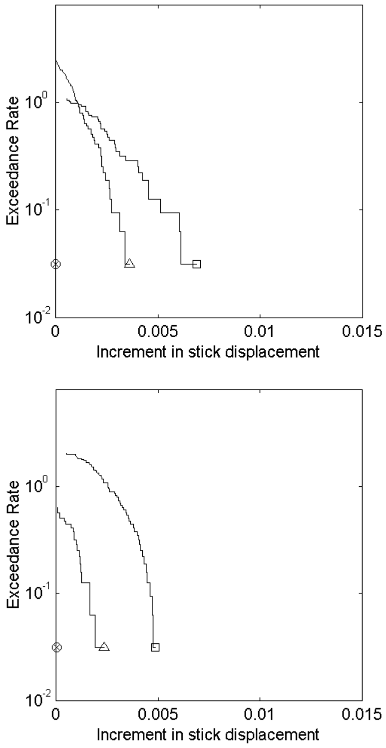


Figure 15; Exceedance charts for case 2 (horizontal gusts included)

6 Conclusions

The paper has described the development of firstly a generic pilot model, SyCoS, to predict the control activity required to fly along a prescribed flightpath and secondly, a method for predicting workload via a Wavelet Analysis. The following are the main conclusions from the work so far :-

i. the SyCoS model has been shown to successfully pilot a fully non-linear helicopter model through basic manoeuvres.
ii. the structure of the SyCoS model allows for corrective actions to be made to external disturbances such as airwake and turbulence.
iii. non-linear components have been added to SyCoS to add more realism to the prediction of collective activity
iv. SyCoS has been applied to the simulation of helicopter / ship operations with the intention of developing a method to calculate Ship Helicopter Operating Limits through desktop simulation.
v. combination of SyCoS and Wavelet Analysis will allow limits on torque, pedals and workload to be predicted without the need for piloted simulation.
vi. Wavelet Analysis has been shown to re-produce the pilot's subjective rating to within one HQR point in most cases.

7 Future Work and Recommendations

It is considered that a valid method has been put in place to allow Ship Helicopter Operating Limits to be calculated through desktop simulation. Further work is now required to fine tune this method and demonstrate its overall fidelity. In particular, further work will be conducted to increase the realism of the prediction of cyclic control activity.

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