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Mathematical analysis of human factors using experimental parameter identification of human behaviour model

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This paper discusses the results of measured pilot response to a sudden parameter change while flying an aircraft. Historically, the American scientists McRuer and Krendel tried to describe all possible characteristics of a human behaviour model using transfer functions and time constants by applying them to physiological human behaviour. Authors analysed those models and used analytical model of human behaviour based on the basic elements of automated regulation. With the fast advancements in technology, especially in simulation technology, it is easy to verify practically all theoretical suggestions, approaches and models [1]. The aim of this verification is to imitate human behaviour while controlling a machine – including an aircraft – and to reduce the influence of human error while flying an aircraft. All the tests described were conducted on a Cessna 152 flight simulator, at the University of Hertfordshire, Hatfield. Students of Aviation Studies, with several tens of flight hours in real aircraft, were tested. The tests consisted of a sudden step change in altitude. The measured results were then mathematically analysed in the MATLAB®simulation environment. The calculated results confirm that the experimental measurements can help in other stages of research activities The individual transfer function parameters have obtained concrete numerical value.

Keywords: Human Behaviour Model Pilot Modeling, Transfer Function Human Factors Flight Simulator X-Plane MATLAB®, System Identification Toolbox™, Parameter Identification

1. INTRODUCTION

In today's automated and digitalized world the stress is put on the development of both computers and artificial intelligence. However, a pilot or an operator is an indispensable part of any aircraft flying. Only time will tell if a pilot (operator) could be fully replaced by a machine and if so it will take a very long time. That's why the aircraft's manufactures started to do research on the influence of the human factor.

Some authors [2] generally define the human factor in the form of SHELL model. The human factor influences many processes of aircraft flying from the very beginning of entering the cockpit, through taking off and landing procedure to stopping the engines. SHELL model is composed from several parts and for our research purposes the interaction between man (L - Liveware, in the middle of the model) and machine (H - Hardware) which means aircraft is important. Taking the human efficiency into account the emphasis is put on the ergonomics of the controls in the cockpit, the manipulation space of the pilot, the method of entering the pre-flight data into the Flight Management System, autopilot controls and others avionic systems. These factors are supposed to make a pilot's work easy and eliminate his psychological and physical workload while flying a plane [3]

How will the pilot react in an unpredictable flight situation [4] if one of the automated systems were to cut off or if a sudden change of position angles would accrue [5] due to weather conditions? The authors of this paper focused on weather conditions causing a sudden change of altitude or other flight parameters. Using experimental measurements from the flight simulator a model situation was created where the pilot's task was to react as fast as he could and put the aircraft back to the same altitude using only an elevator. The data from this flight simulator was analysed. Only the most accurate and interesting flight results was used like an input data into the System Identification Toolbox and MATLAB®environment with use an algorithm to identify parameters of a transfer function (1).

The reason is that the parameters and time constants of the pilot (as a human) are time variables and are influenced by many unpredictable factors such as the pilot's experience, tiredness, stress, surrounding noise and other random aspects which can arise during the flight. To determine a human's behaviour, within a control loop, in a given flight mode is possible only after obtaining a correct pilot response in a given mode in the correct time. The authors identified, modelled and simulated these responses by measuring the pilot's responses in a flight simulator. From this data the best realistic time constants representing the pilot's behaviour were found. The future vision of the authors is to set limits to all the pilot behaviour time constants depending on the level of their experience and psychological and physical condition.

2. MATHEMATICAL MODEL OF A PILOT BEHAVIOUR

A human-pilot character in the control system can be represented by a variety of complex block diagrams which more or less describe most of the possible factors affecting human behaviour. Generally, it is not possible to create one universal model fully describing the human dynamic character in various situations during a flying process. Human behaviour can be with certain inaccuracy, concisely described by a block diagram as shown in figure 1:

There are three mutually connected "blocks". The input – sensors are the pilot's sensory organs, from where the detected information goes into the central nervous system. The average speed of emotion transmission is in the range of 5 to 125 ms^{-1}. In an automated control system this transmission feature can be represented by a transport delay. The response time mainly depends on the level of the pilot's internal stress, the actual pilot's condition and perhaps also on some other factors. Sensory organ features are in real life represented by a sensitivity level, adaptation ability and the ability to mutually cooperate. After processing the received signal a command to hand or leg muscles is sent to adjust the elevator, aileron and rudder deflections. For maintaining the requested flight parameters the pilot uses three different types of regulators [6, 7]:

- Predictive regulator, keeping the required flight mode based on the pilot's received visual and sensory perception of the flight.
- Feedback regulator, created by correct visual and sensory perception of the required flight mode.
- Precognitive regulator, recalling the learnt maneuver from memory, i.e. a clear sequence of elevator, aileron and rudder deflections making the required aircraft movement.

It is very complicated to describe human/pilot behaviour mathematically. So far, there is no complete list of all biological and physiological processes of the human brain and therefore it is no possible to create a comprehensive list describing the human thinking processes upon which pilot behaviour is based. A human – as a pilot – is able to adapt and fly various types of aircraft after a certain amount of training. A human can also manage complicated situations by changing and adjusting his behaviour based on current conditions, and is capable of changing his strategy and tactics based on visual input information. The decision making process and choice of future action is, more or less, individual, especially in emergency situations

When analysing any aircraft control with human behaviour it is essential to take into account that all the human features are time variables and dependent on the actual pilot condition, psychological state, tiredness and ability to adapt to a new situation. This is all affected by long-term habits, education, training and flight preparation. To create a mathematical model of a human in such a moment is not easy. For modelling human behaviour a linear model is often being used (which is not quite correct for example regarding output value limitations) with a transport delay defined by a transfer function as follows [8–12]:

$$F(s) = \frac{Y(s)}{X(s)} = K \frac{(T_3 s + 1)}{(T_1 s + 1)(T_2 s + 1)} e^{-\tau s}. \qquad (1)$$

where:

K - Pilot gain represents pilot habits for a given type of aircraft control. If the pilot takes larger than necessary intervention action or if a change in system amplification occurs during the regulatory process, the system could become unstable.

T_1 - Lag time constant is related to the implementation of learned stereotypes and pilot routines. When the pilot repeats certain situations several times, it leads to stereotypes and learned habits. Eventually the phase arrives where the pilot gradually eliminates conscious brain activity.

T_2 - Neuromuscular lag time constant represents the pilot's delay in activity caused by the neuromuscular system. The neuromuscular system in its entirety includes muscles and sensory organs working at the spinal level (spinal cord). Through the spinal cord the brain receives information and can react to the external environment. The central nervous system and peripheral nervous system provide informational links between the organisms with the external environment and continuously regulates processes within the body.

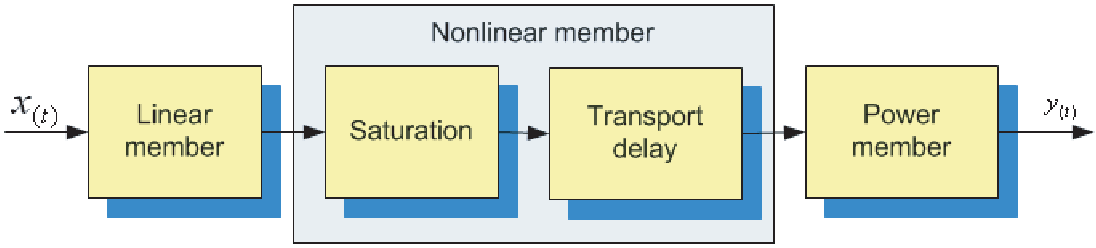

Figure 1 The human behaviour model from an automatic regulation point of view.

T_3 - Lead time constant is related to the experience of the pilot. Reflecting the pilot's ability to predict a control input which means to predict the situation that may occur. Estimating and predicting the future state is the ability to imagine the future steps and states of the surrounding area. This level represents the highest level of situational awareness when the pilot has reached such knowledge of the state and dynamics of individual system elements that he has the ability not only to understand the current situation, but also he is able to determine future situations. The pilot obtains this ability via training and experience.

τ - This time constant indicates the delay of brain response to the pilot's musculoskeletal system and eye perception. The transport delay depends on the current state of the neuromuscular system and also on the physical and mental condition. Fatigue may significantly increase the value of transport delay and the regulatory system could become unstable.

This shape of transfer function is based on the assumption that the pilot is behaving in a linear manner, i.e. as a linear element. In a real regulation circuit there are always, up to a certain extent, non-linear elements, as it is in human-machine systems. In publications [6, 13] there is an example of an extended transfer function considering a nonlinearity of actuator. Generally, the extended transfer function is as follows:

$$F(s) = \frac{Y(s)}{X(s)} = K \frac{(T_3 s + 1)}{(T_1 s + 1)(T_2 s + 1)} e^{-\tau s} + \text{remnant function}, \quad (2)$$

The design of the remnant function is complicated procedure because it attempts to represent the non-linear component of pilot behaviour. It is primary source is the pilot's ability to learn and adapt which results in non-linearity and non-steady behaviour. The secondary contribution comes from such things as the experimental setup and experimentally injected noise that affect pilot response to other inputs. However, careful selection of the pilot model and task can help minimize remnant effect [12].

In real life, the human operator's control action is not linear and is also influenced by negative aspects of non-linear elements such as hysteresis, insensitivity, saturation or non-linear variable amplification. It is challenging, not only to identify these elements but also to categorise or allocate them into a regulation circuit with multiple feedbacks.

Many scientists use a transfer function for pilot compensation response as shown in (1). This equation was first published by the English scientist Arnold Tustnin studying the characteristics of a human regulator with manual feedback control. Similar physiological analysis of time constants in the aforementioned human regulator transfer function was done in the 1970s by the American scientists McRuer and Krendel for autopilot models [13].

According to [6] there are many publications describing scientists assigning individual time constants to physiological processes. However, there are many opponents stating that this approach is not correct as neuro-motive functions and central nervous system functions are mixed together.

Figure 2 shows the key control system blocks with the pilot and autopilot sharing control of the aircraft. The pilot is the main control element knowing the flight task. All the automated functions are adjusted to this condition, including the pilot control options and Flying Control Systems. The pilot's response is, based on the pilot's flight experience and skills, processed at the sub-conscious level using higher brain functions. This information is then transferred via the neuromuscular system creating a physical response. The pilot then manoeuvres the aircraft using appropriate aircraft elevator deflection. The pilot then senses the resultant aircraft movement via many different senses as feedback. This feedback is then processed again by the neuromuscular system and the aircraft elevator deflections are adjusted accordingly. The Flight Control System [15] significantly simplifies the flying process for the pilot by checking and adjusting a whole range of flight parameters from damping fast oscillations to flatter damping.

3. METHODS FOR EXPERIMENTAL PARAMETER IDENTIFICATION OF TRANSFER FUNCTION

Due to the fast development of simulation tools and information technology, the analysis of human behaviour whilst flying an aircraft can now be very sophisticated. Therefore the accuracy of the individual described models becomes a major factor. The following mathematical analysis is therefore dependant on the correct choice of studied parameters and simulation environment set up.

3.1 Algorithm for Experimental Identification of Transfer Function Parameters

It is convenient to refine the human behaviour model parameters using experimental measurements of human response

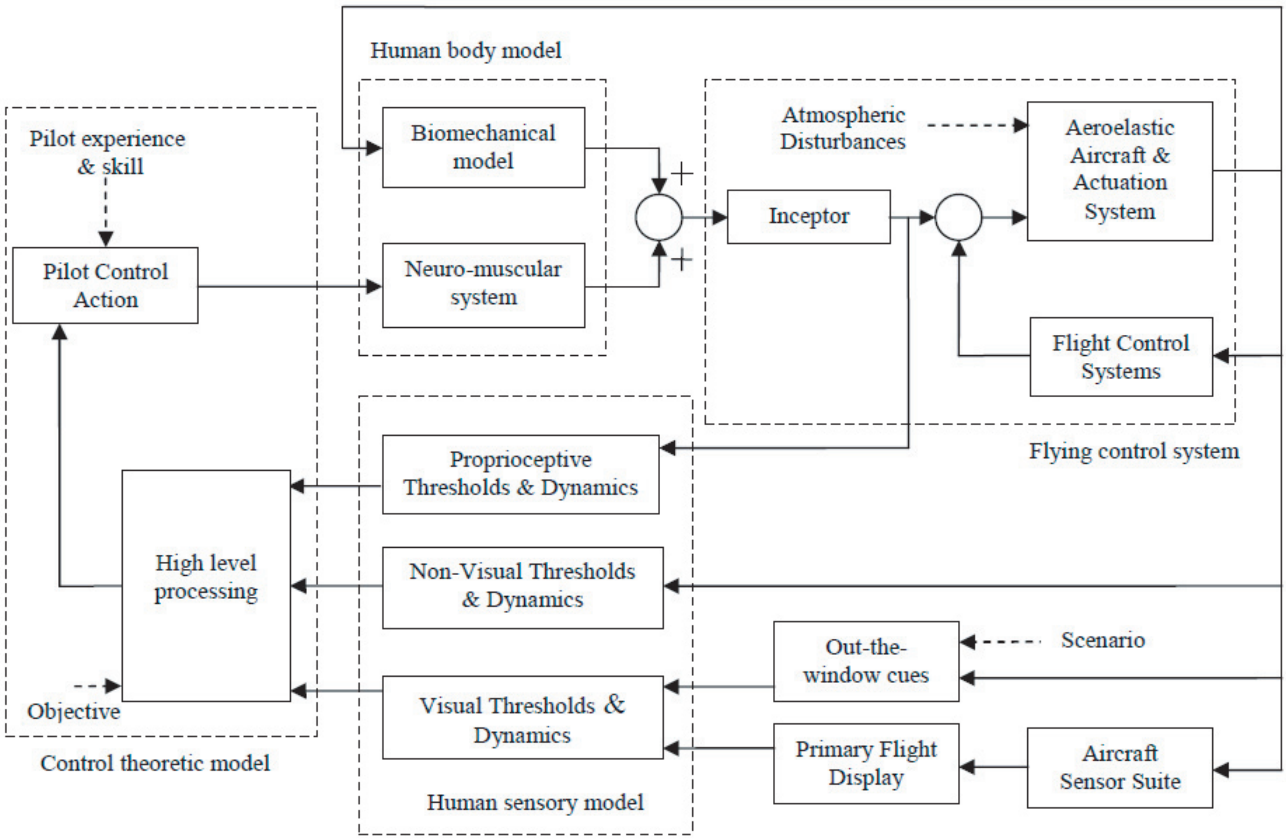

Figure 2 Block diagram representing the pilot-vehicle system under manual control [14].

to external stimulus. The tested pilot is watching the external stimulus, i.e. the step change, on the simulator screen or instrument panels and by using the control yoke, the pilot attempts to reach the required value of the step changed parameter. The time flow of the control yoke was then input into a PC and recorded together with the external stimulus value. Both of these entries were then used in experimental mathematical identification methods.

Depending on the chosen transfer function type of the pilot behaviour model it is possible to determine time constants in real systems using mathematical experimental identification methods, as was successfully done, for example, in [7, 11]. If the input and output signal and the approximate shape of the transfer function are known, the above mentioned methods can be used to refine transfer function parameters. It is also convenient to use the MATLAB simulation environment already containing some functions for necessary calculations.

Function fminsearch searches for a scalar function minimum of multiple variables [17]. This function was used to create, and later alter, the parameter identification algorithm of the pilot transfer function. The algorithm is as follows:

$$F_{ei} = \frac{a_1 s + 1}{b_2 s^2 + b_1 s + 1} \quad (3)$$

Regard to the equation (1) the algorithm parameters are:

$$a_1 = T_3, \quad b_2 = T_1 T_2, \quad b_1 = T_1 + T_2 \quad (4)$$

with a defined criterion condition:

$$f_{\min} = \sum (y_{id} - y)^2. \quad (5)$$

However, this algorithm can't calculate transmission delay. Therefore, the program was supplemented with a simple subprogram searching for the pilot response initiation (when the output value wasn't zero, i.e. was higher than a very low given value). After the time delay evaluation, the input impulse of the identification algorithm was shifted to the beginning of the response initiation.

3.2 System Identification Toolbox™

One of the other possible methods how to calculate parameters of pilot behaviour model transfer function is using MATLAB toolbox - System Identification Toolbox. This System Identification Toolbox designs mathematical models of dynamic systems from measured input and output data but is not include in basic MATLAB package. The toolbox performs grey-box system identification for estimating parameters of a user-defined model. This toolbox are using for development models of a black-box system without having to fully characterize the mathematics governing the system behaviour for example – System Identification, Developing a Model Using White Noise Data, Prefiltering, Data Processing, Input Design, Model Structure Selection, Prediction Error Identification and more. The input data consisted of the measured changes of altitude depending on control yoke deviation. The output data consisted of measured control yoke deviation in the longitudinal direction.

The toolbox uses a graphical user interface (GUI), which is launched by command ident in MATLAB command window. GUI which is shown in the figure 3 facilitates work with organization of data and models. It is possible to use time-domain and frequency-domain input-output data to identify continuous-time and discrete-time transfer functions, process models, and state-space models.

The GUI window is schematically divided into data section, models section and working space. The data section is situated in the left, where is possible to import time-domain and frequency-domain input-output data. Function „Time plot“, shows input and output data waveform. In the right of figure 3 is models section which is used for import models from MATLAB. Those models from MATLAB serve for example for comparison of two results obtained using two different identification methods.

There are also so called „Model View Windows“, which corresponds to six views for examining models. It is possible to generate these views for selected models by selecting the corresponding check box in the Model Views area of the GUI. To select the models which will be include in the plot just click their icons in the Model Board(s).

- Transient response shows the transient response of the selected models. It is possible to choose between displaying impulse and step responses.

- Frequency response shows the frequency functions of the selected models. The plot is known as a Bode plot when the amplitude and frequency scales are logarithmic.

- Zeros and poles show the zeros and poles of the selected models. The poles are marked by x while the zeros are marked by o. Discrete time zeros and poles at the origin are not displayed.

- The plots of Noise spectrum show the disturbance spectra of the selected models. Cross spectra between different outputs are not accessible.

Among the most important functions belong „Model output“. By clicking check box the plots will show the simulated (predicted) outputs of selected models. Depending on the character of the validation data the plot takes somewhat different forms. Regard to measured data from the flight simulator the authors were used time domain data form where the simulated or predicted model output is shown together with the measured validation data. The percentage of the output variations that is reproduced by the model is displayed at the side of the plot. A higher number means a better model. In the middle of GUI „To workspace“ and „To LTI viewer“ boxes are situated First function moves model to MATLAB workspace and second function serves for graphical analysis.

If the data are correctly loaded into the toolbox it is possible to start with data processing. Clicking on the button „Estimate“ the menu is appears and from the options the „Process Models“ is selected. Figure 4 shows the “Process Models" window where the shape of transfer function is selected. This window provides a number of options, for example setting of initial guess, bounds, the number of iterations, minimization criteria.

4. DESCRIPTION OF THE EXPERIMENTAL WORKPLACE AND THE MEASURING METHODS OF PILOT RESPONSES

4.1 Experimental Workplace

The flight parameters and the generally measured values for transfer function parameter identification were measured during a three-month exchange program at the University of Hertfordshire, Hatfield. The university has a laboratory with flight simulators used for pilot training as well as for research purposes. The mentioned flight simulator is primarily intended for pilot's preparation especially for training flight procedures before flight, during and after the flight. The lab is under the auspices of a specialist in automated aircraft control. Our flight tests have been allowed only with good will of Dr. Rashid Ali. Based on his expert advice a Cockpit Simulator Cessna 152 was selected for our testing, see image 1.

The flight simulator Cessna 152 consists of a Cessna 152 aircraft fuselage with two seats for crew. This fuselage is anchored to a static base fixed to the floor. The flight simulation was done by three projectors, projecting images onto a parabolic wall. Based on the research needs software X-Plane 9 from Laminar Research Company was used. The main advantage of this software is its precise and detailed simulation of flight physics for all individual aircrafts. The simulator as a whole is controlled by a PC - also called an Instructor Station. An instructor sitting at this station can change any flight parameters during the flight simulation. All control elements, flight instruments and control stick inside the cockpit are connected to the instructor station. The pilot can fully focus on flying the plane while the instructor can see all the real time parameters on his monitor.

4.2 Measurement Methodology of the Pilot Response

The tested pilots were around the age of 23 and all holding Commercial Pilot Licenses (CPL). They were American university students on an exchange program at Hatfield, studying their final year of pilot studies. They all had several hours of flight experience on the Cessna 152 and Cessna 172 aircrafts. All tests were conducted in one day.

As the earlier created algorithm for transfer function parameter identification was made to process the input signal as a unit step function, the authors of this paper chose a unit step function (from a constant flight level) as an input signal. The test was conducted as follows. After an initial induction and simulator training the pilot was explained the test procedure and his task. The pilot's task was to take the plane into a straight horizontal flight. The instructor suddenly changed the aircraft altitude by 100 feet. In real situations such a decrease or increase in altitude can be caused by strong weather conditions or turbulences. The pilot's task was to put the aircraft back to the original altitude as fast as possible and stay there. He could do this by using only the aircraft elevator controls. The engine thrust was constant. The test was conducted with the same pilot several times in the same manner. Also

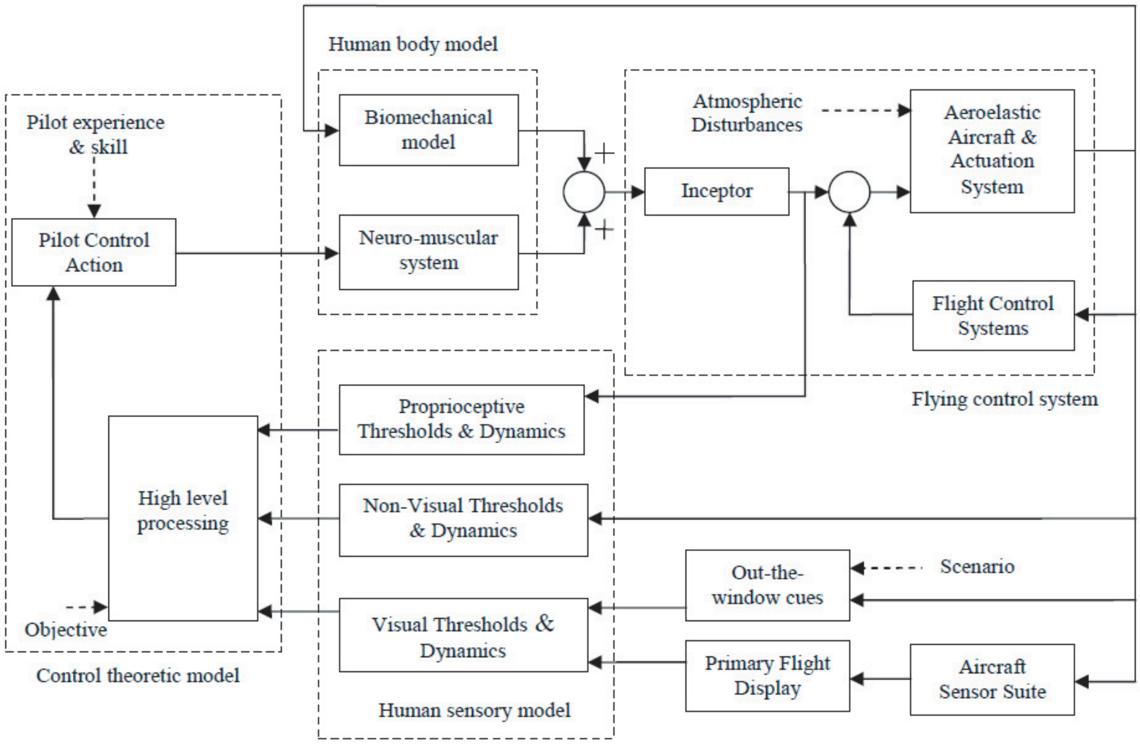

Figure 3 Graphical User Interface (System Identification Toolbox).

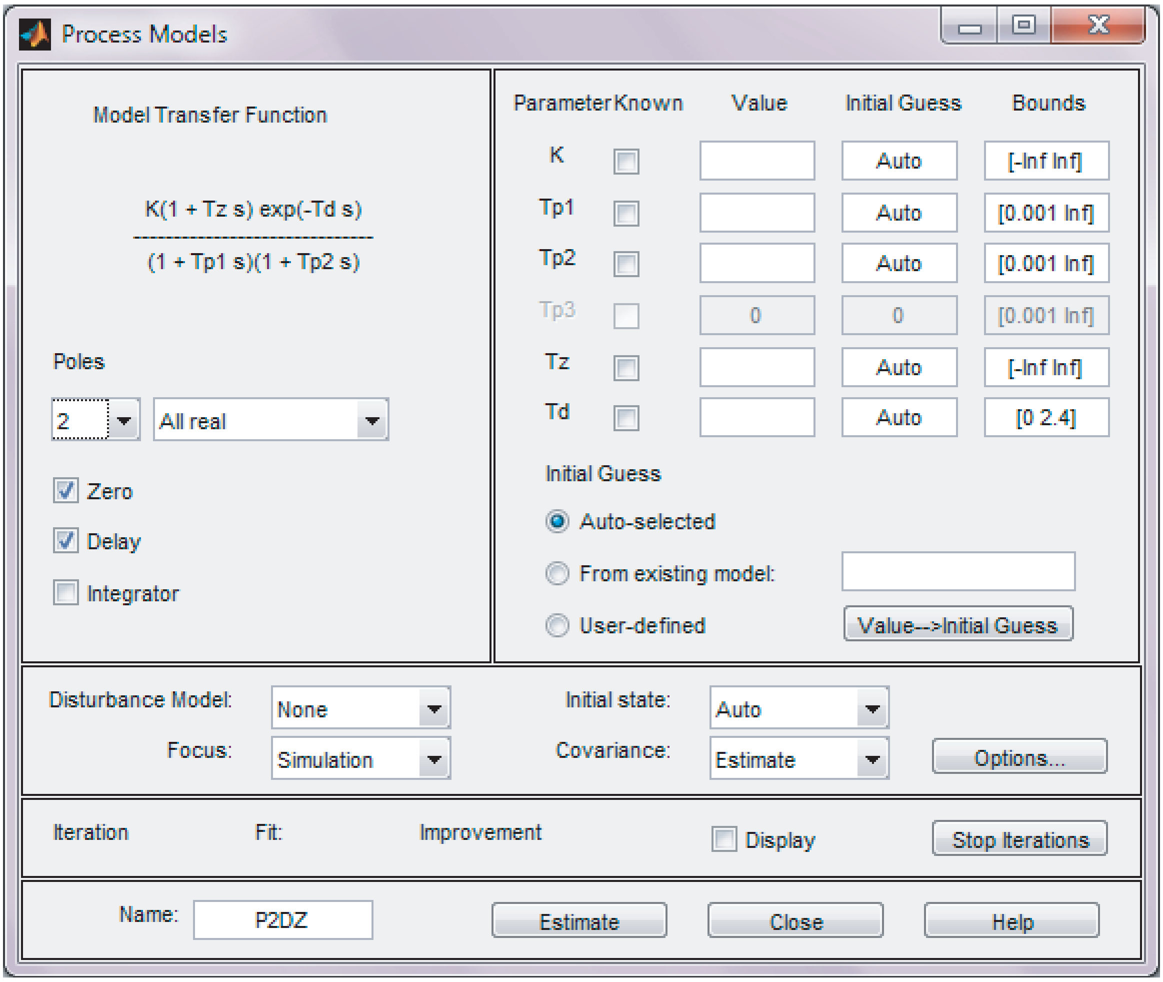

Figure 4 Graphic environment for choosing the shape of transfer function.

Image 1. Cessna 152 Cockpit Simulator (University of Hertfordshire)

the other pilots were tested in the same manner and under the same conditions. All of the data was recorded and stored in the instructor station.

4.3 Factors Affecting the Measurement

Some limiting factors, occurring during testing, affected the measured results. Firstly, in real situation the pilot senses any aircraft change by his senses organs. This cannot be ensured when using a simulator fixed to the floor. The tested pilots only sensed the altitude change visually by watching the altimeter in the cockpit and by expecting a sudden change. This fact largely influenced (increased) the time constant of the pilot transport delay between sensory perception of the change and a brain response.

After result evaluation and consultation with the pilots about the flight process the pilots talked about greater control sensitivity of the simulator compared to a real aircraft. Another factor lowering the realistic feel of the flight was a small observation angle as seen in image 1. Due to the distance and curvature of the screen used for image projecting the pilots didn't have 100% the same feeling as they would in a real aircraft cockpit.

5. DISCUSSION OF THE OBTAINED RESULTS

5.1 Input Data – Unit Step Function, Output Data – Flight Altitude

The measurements from the simulator were analysed using an algorithm for experimental identification of transfer function parameters. The authors have already created and tested such an algorithm. However, this was the first time realistically measured data from a simulator was applied. Four pilots were tested and each of them had to deal with four to six different changes of a flight altitude. The two cases below are the two best pilot's manoeuvres, one going back up to the original altitude and one going back down to the original altitude. The last case demonstrates a badly conducted manoeuvre and the imperfection of the identification algorithm.

The following figure 5, 6, and 7 show the waveforms of pilot response to 100 feet large step input. Response also in feet, on the Y axis represents the altitude change which is obtained from the pilot reaction to step input. Figure 5 shows an almost perfect pilot manoeuvre when returning to the original altitude. This was the pilot's fourth trial which proves that the more trials the better the pilot gets. The pilot was able to recover the original altitude in 14 seconds only by using an elevator control. Undoubtedly, the time in which the pilot is able to recover the original altitude also depends on the type of aircraft. The pilot's response is copying the graph of PID regulator to which the pilot can be compared. Taking in account a standard deviation, the pilot's response chart is almost perfect. To a person's naked eye, there is almost no difference between the pilot response curve and the curve created by the mathematical model for identification of transfer function parameters.

Figure 6 shows the best pilot's manoeuvre when descending to the original altitude. This result is absolutely unique. In the other tests none of the other pilots matched even slightly such a response curve. The identification algorithm approximated the pilot's response to the unit step function reasonably well. In table 1 important identification algorithm parameters are shown after several hundreds of iterations and also the pilot behaviour time constants are shown, i.e. their product and their sum.

In figure 7 there is clear evidence of the pilot's effort to come back to the original altitude. In this case the altitude recovery took longer and two aircraft oscillations occurred. Similar aircraft oscillations were found at least once for each pilot in their attempt to quickly descend back to the origi-

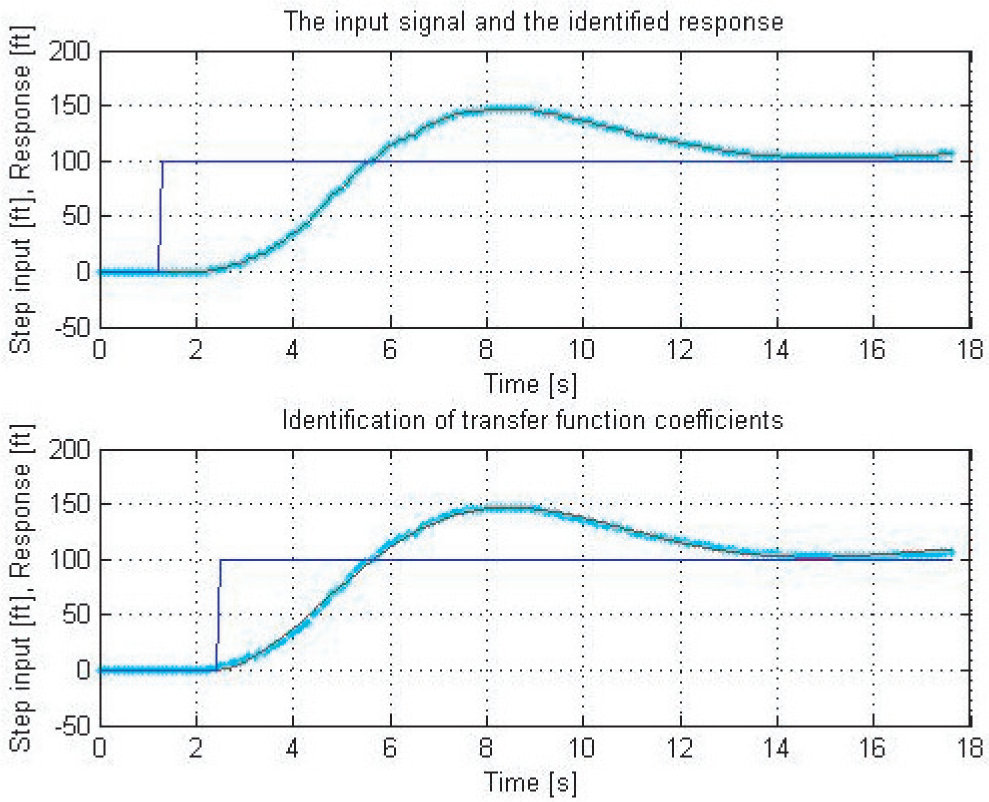

Figure 5 Pilot's response to a unit step function – ascent to the original altitude.

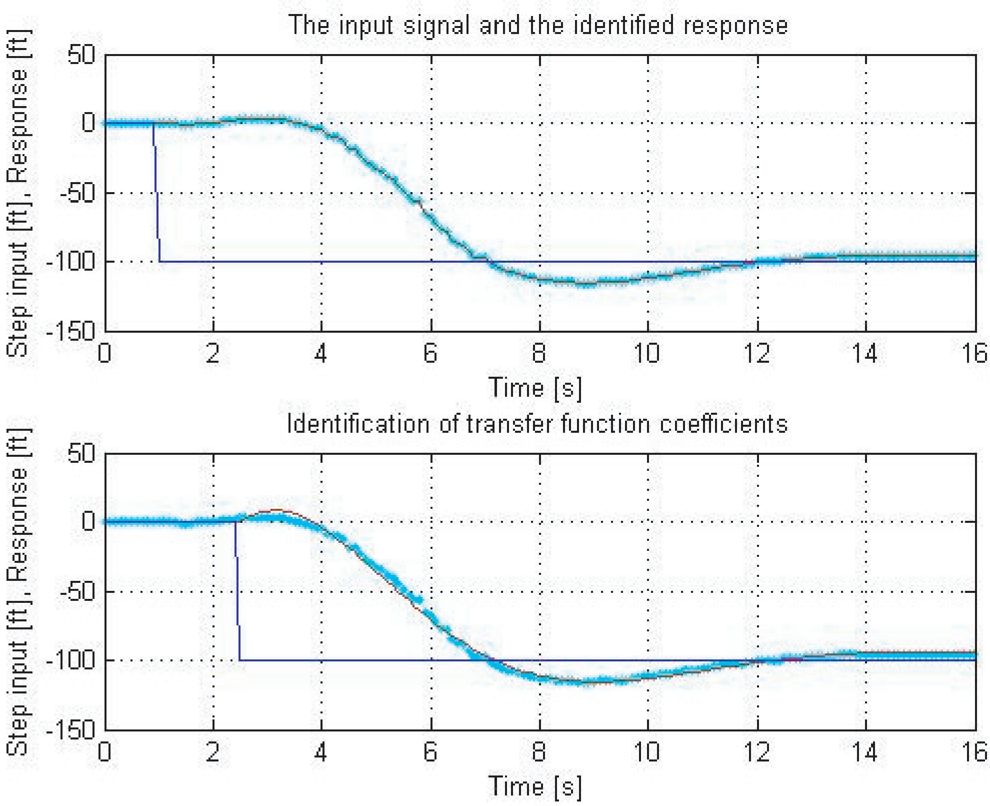

Figure 6 Pilot's response to a unit step function – descent to the original altitude.

nal altitude. The reason is that when descending the speed is naturally increasing and therefore the recovery manoeuvre is more difficult and the controls are more sensitive. It is also important to note that applying a 2nd order transfer function for this case of pilot response was inadequate. All the simulation parameters and the pilot time constants from this analysis

Table 1 Parameters of the identified transfer functions – parameters corresponds with (1) and (3).

Figure	K	τ	$T_3 = a_1$	$T_1T_2 = b_2$	$T_1+T_2 = b_1$
5.	1.12	1.1	0.28	3.46	1.32
6.	0.97	1.4	−0.78	2.72	1.60
7.	1.20	0.8	−1.58	4.11	5.30

Table 2 Parameters of the identified transfer functions - parameters corresponds with (1) and (3).

Figure	K	τ	$T_3 = a_1$	$T_1T_2 = b_2$	$T_1+T_2 = b_1$
8.	−1.094	0.690	0.204	0.0212	0.366
9.	−1.070	0.683	0.350	0.0162	0.308

were disproportionally higher than those in the two cases mentioned above. An improvement could be reached by applying a higher order transfer function, but those results would not be comparable with the other measured results.

All the conducted tests show fairly higher time delays than assumed in theory [6]. That is caused by a wide range of factors affecting both the method of testing and assessment and the identification algorithm itself. There are two main reasons for these higher delays. Firstly, that the pilot was detecting the altitude change only visually. Secondly, the pilots were not informed when the altitude would suddenly drop or increase by the 100 feet and thus taking longer to analyze the situation and react appropriately. The authors also discovered, from the identified data, that aircraft dynamics also play an important role in getting a higher time delay. It is clear from the measured control stick responses that pilots started the returning maneuver about 0.2-0.3 sec earlier than the plane started to ascent or descent. The last but not least factor affecting the time delay is the sampling frequency set at 0.1 sec disallowing more accurate time delay analyses.

5.2 Input Data – Flight Altitude, Output Data – Control Yoke Deviation in Longitudinal Direction

In the past, the authors conducted many simulations and tests using human behaviour time constants taken from available literature. A built-in toolbox (System Identification Toolbox™) in the MATLAB®simulation tool was used to calculate the transfer function model parameters.

A second method for transfer function parameter calculation utilised the above created algorithm. This algorithm was used previously to identify pilot behaviour model parameters, however, only theoretical time constants [4, 7, 11] were used in these calculations. In this study the focus was on verification of algorithm credibility followed by an implementation of the measured data into this algorithm. The input and output data were identical to data from the System Identification Toolbox. A sampling frequency of 0.01 seconds was used for both simulations. There were 1648 input data samples and 1648 output data samples available, with a corresponding simulation time of 16.47 sec. This is the time when the transition-compensation movement finished.

Figure 8 shows the input and output time flows and also the final curve that was calculated by the identification algorithm after 1201 iterations. The algorithm is, up to a certain degree, able to calculate the transfer function of a dynamic system, based on input and output data. It uses the function fminsearch from the MATLAB®program library.

The solid-line curve shows the time flow of the altitude change. To simplify the illustration and the computing operations the graph was scaled down 100times. The instructor unexpectedly lowered the flight altitude by 100 feet within two seconds and the pilot responded as fast and as accurately as he could by ascending back to the original flight altitude. It was clear from the graph that the pilot's response was similar to a single-overshoot PID controller.

The dash-dotted-line curve, in the anti-phase of the solid-line curve, shows the control yoke movement in the longitudinal direction. When the pilot realised the sudden altitude change, he moved the control yoke to the maximum and brought the aircraft back to its original flight altitude. The pilot started to fine-balance the flight relatively late and due to aircraft momentum one oscillation occurred. After this the pilot was able to stabilise the aircraft to the original flight altitude.

The graph clearly shows the first time constant of the pilot – the Transport Delay, without any calculations. The transport delay is relatively high as there are many factors disturbing and affecting the testing procedure and its evaluation. The time delay is mainly caused by the fact that the pilot only registered the altitude change visually on the altimeter in the cockpit. The pilots expected a sudden altitude change, but they were not informed whether it would be an increase or a decrease by 100 feet and thus it took some time for the pilot to analyse the situation and respond correctly. In other situations, for example oscillation damping by the pilot, such a time delay would be unacceptable. This time delay value is too close to the critical value (0.9 sec) and when exceeded a destabilisation of the 'pilot-aircraft-automated flight control' closed loop occurs [16]. The pilot could generate a so called, pilot induced oscillation (PIO) dangerous for both flight safety and the airframe itself.

The final calculated curve is shown as the dashed line. It is clear, that the algorithm is able to follow the trend of the curve until the pilot pulls suddenly on the control yoke and holds it to the maximum. At this point the elevator control movement becomes limited, i.e. non-linear. The algorithm can't handle non-linear movement and nor can it come back and follow the curve trend. The algorithm only partially follows the control yoke trend curve. The parameters of the calculated transfer function are shown in table 2

Figure 9 shows the final curve acquired from input and output data. As mentioned earlier in this article, the identical input and output data were entered into the System Identification Toolbox so that both final transfer functions and both methods of simulation could be compared. The trend of the final curve is almost identical to the identification algorithm trend. The non-linearity of the sudden pull on the control yoke and reaching the top-limit position is shown in the graph and the System Identification Toolbox also can't handle this non-linearity. The final values of the transfer function are shown in table 2

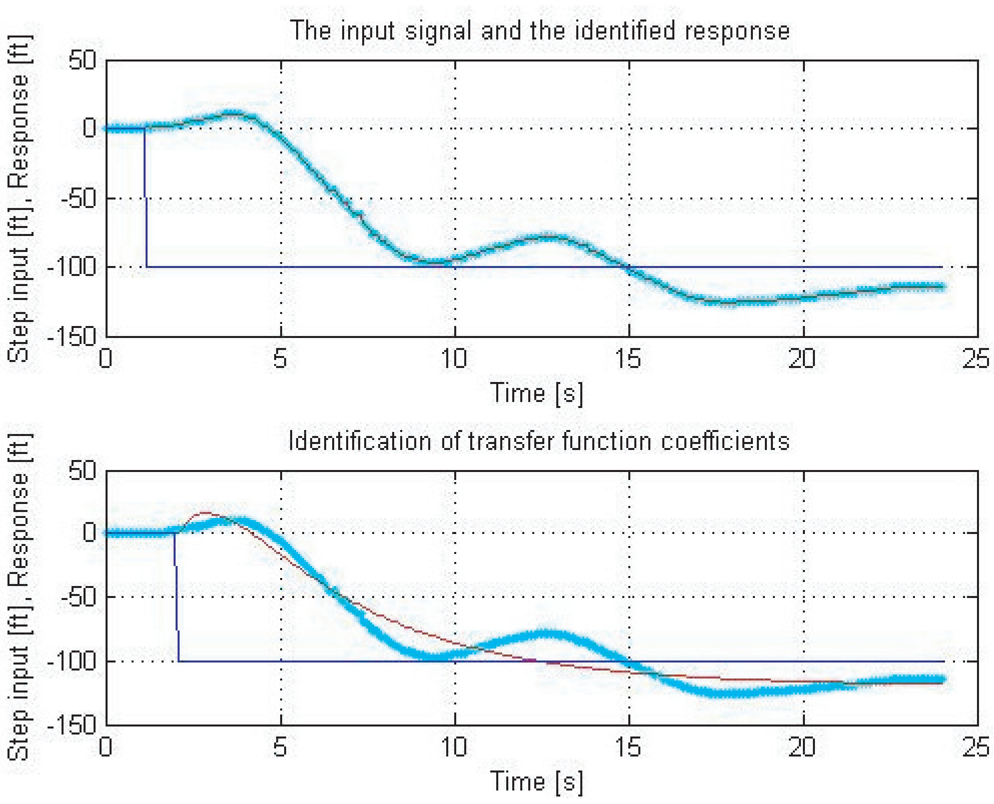

Figure 7 Pilot's response to a unit step function – descent to the original altitude (oscillation).

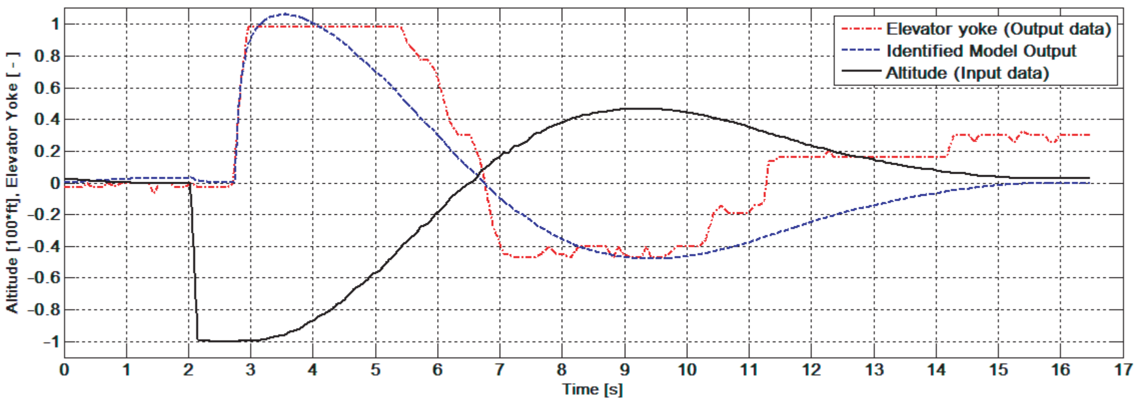

Figure 8 Identification of Transfer Function Coefficients (Identification Algorithm).

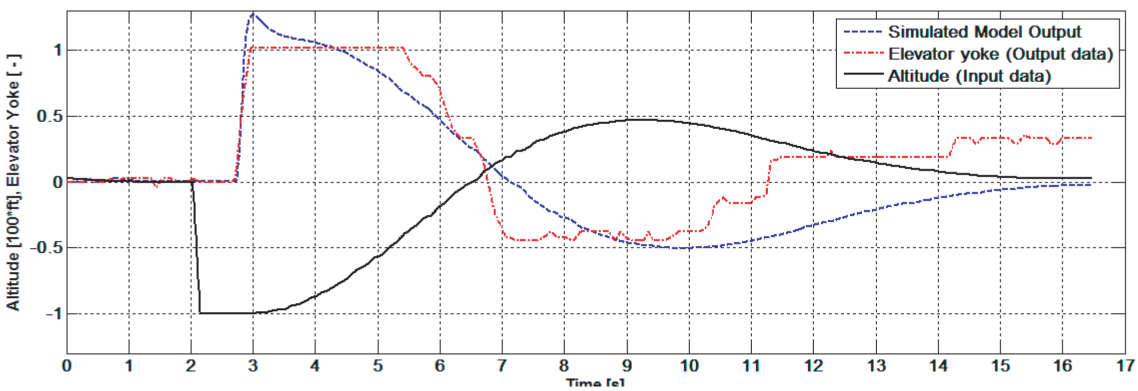

Figure 9 Measured and simulated model output (System Identification Toolbox™).

6. CONCLUSION

The authors conducted many tests on the Cessna 152 flight simulator and other simulators including computer simulations of human behaviour whilst flying an aircraft. The data from these tests were then used for transfer function parameter identifications of a pilot behaviour model. As the amount of data was enormous, only the most important data and the most interesting pilot responses were presented in this article. By comparing the measured output values of the time constants with the theoretical limits of the time constants, it can be said that it is possible to simulate a real pilot's behaviour quite accurately.

Currently, the authors are preparing an aircraft simulator experimental site for measuring human/pilot behaviour whilst flying an aircraft in different modes and in different types of aircraft.

There is one important factor in professional pilot training and that is the amount of flight hours (practical flying experience). The test results clearly showed that the pilots were getting better and better with each test, shortening the time in which they brought the aircraft back into its horizontal altitude. This negative factor will be in the future compensated for by having longer pilot training courses. Practical flying experience negatively influences both the predictive time constant of pilots, depending on their experience, and pilot's lag time constant, connected with learned manoeuvre stereotypes.

Determination of the boundaries of transfer function parameters allows the application of new trends in pilot training. From the long term viewpoint for example the change and modification of pilot training or pilot regimen and proper motivation can help minimize negative influence which effecting pilot activities and reactions. Knowledge of the parameters of pilot behaviour model can be also used in the early stage of automatic control systems design. In some case may happen that the pilot intervention is in the same phase as automatic control systems. Subsequently so-called pilot induced oscillation will have negatively effect on the flight safety. If we will know the exact values of the parameters the software or hardware can prevent this situation. Predictions of human behaviour during aircraft flight control are nowadays a necessary condition for a successful reduction in the human error factor in aviation.

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