Measuring Human Response to a Visual Stimulus Using a Joystick

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Abstract: - Measuring the human response to a visual stimulus is the next necessary step for future flight simulator testing. Two different methods: an identification algorithm, designed by the authors; and a simulation system MATLAB add on - System Identification Toolbox, were used. The results from both methods, i.e. the individual parameters of the transfer function for the pilot behaviour model, were practically identical. This proved that both methods are credible and fully suitable for this type of input and output data. Individual time constants represent the joystick movement that is dependent on the current psychological and physical state of the tested person. Using time constants is the easiest way to read Transport delay, without any mathematical functions, and to see the difference between a person with fast and slow reflexes. Having such mathematical formulas for analysing the measured input and output data ready, these methods can be used in the future to analyse the acquired data from flight simulators.

Key-Words: - Human response, joystick, human behaviour model, mechatronic system pilot–aircraft, MATLAB®, System Identification Toolbox.

1 Introduction

Nowadays, it is easy to find many publications regarding general human/operator factors [1]. However, there is not much information and material available that focuses on the modelling and simulation of pilot behaviour, especially of a mechatronic system pilot-aircraft-autopilot.

To determine an alternative mathematical model of pilot behaviour whilst flying an aircraft is, from the automated regulation point of view, a very difficult and extensive task. The reason is that the parameters and pilot (human) time constants are time unstable and are influenced by many unpredictable factors. For example: experience, tiredness, stress, noise, etc. Therefore, analysing human behaviour in a regulation loop for a selected flight mode is only possible after gaining some regulation results first - providing information about the human ability to react correctly and on time in the given flight mode.

The human/pilot is, after being trained on a certain aircraft type for different complicated situations, able to adapt and manage certain flight situations. The human is also able to adapt and change his behaviour according to the actual conditions. He can change flight strategies and tactics based on visual information. The decision making process and responses are, to a certain extent, individual - especially in emergency situations.

As aircraft electronic systems are getting more and more reliable and having multiple back ups, a large percentage of aircraft accidents are caused by crew mistakes [2]. That is why it is important to study this topic in more detail and many research teams are studying this issue from different angles.

2 Theoretical Description of a Transfer Function for a Human Behaviour Model

It is very complicated to describe a human pilot mathematically. As all the biological and physiological processes taking place in a human brain are as yet unknown, it is not possible to create a complete list of functions describing the human thinking that all of the pilot’s actions in the pilot-aircraft system are based on.

When considering a human as a part of a control system, it is necessary to take into consideration that all his features are time variables and dependent on
his current condition, psychological state, tiredness, and his ability to adapt to the newly arisen situation. This is all influenced by long-term habits, experience, training, etc.

In a real regulation circuit there are, to a certain extent, non-linear elements. The same rule applies to a pilot-aircraft system. Some scientific publications [3, 4, 5] use transfer functions for non-linear final element actuators as follows:

\[ F(s) = \frac{Y(s)}{X(s)} = K \left( \frac{T_1 s + 1}{T_1 s + 1} \right) e^{-\tau s} + \text{remnant function}, \]  

Where:

- \( K \) - Pilot gain represents pilot habits for a given type of aircraft control. If the pilot over-reacts 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.

- \( T_2 \) - 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.

- \( T_3 \) - 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. The pilot obtains this ability via training and experience.

- \( \tau \) - 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. Increasing the value of transport delay may cause the regulatory system to become unstable [5].

In a real life situation the human operator doesn’t always carry out his control actions according to a linear model, but his actions actually show negative influence of non-linear elements such as: hysteresis, no sensitivity, saturation, or non-linearly variable gain. It is not only difficult to identify these elements, but also to implement or place them into a regulation circuit with multiple feedbacks. The “remnant function” represents some of these negative factors that are added to the linear equation. Identifying non-linearities of the transfer function, or increasing the transfer function order by adding parameters selected by medical specialists, could be the focus of a further future research.

### 3 Test Site and Testing Method

This simple test site (Fig. 1) consists of several components enabling the measurement of human response to a visual stimulus. Firstly, it is a PC, with the author’s own software, for testing and analysing the measured data. Then a joystick is connected to this PC, having the same function and look as the control yoke of a modern aircraft, thus giving the feel of controlling a real aircraft. Furthermore, the test site also has a mobile printer for printing on-line protocols, i.e. the results of individual tests, (used for archiving). These printed test results are also provided to the tested pilots for their own reference. This test site is mobile and is used for human response tests at various technical workshops and conferences. In the future, this test site could be used at various air bases for quick pre-flight tests of the pilot’s physical condition.

![Fig. 1. Test site for measuring human response to a visual stimulus.](image)

The principle of tests for measuring the human response to a visual stimulus is shown in Fig.2. The tested pilot is watching a visual stimulus on a screen that suddenly step-changes and the pilot is trying to match the “deviation” curve on the screen by moving control stick - joystick. The input signal, that the pilot responds to, is a curve that in suddenly step-changed. The tested pilot doesn’t know beforehand whether the step-change will be positive or negative. The pilot must respond to an unpredictable and unexpected situation. The task of the pilot is to copy the step-change as quickly and as
accurately as possible. The joystick movement is read by a linear sensor in two mutually perpendicular time axes. The joystick movement time flow is then transferred into the PC and recorded together with the response speed and step-change size. All of this data, together with the time axis, is then used in the mathematical methods of experimental identification [8]. Although the acquired parameters of these human behaviour models do not represent the full pilot load during a real flight, it is assumed that the parameters are very similar.

Fig. 2. The principle of measuring human response to an external stimulus [6].

4 Human Response to a Visual Stimulus - Test Results

Due to the limited article space, the authors presented only a part of all the test result graphs. The measured pilots reacted to the step-change by pushing or pulling on the joystick in order to zero the deviation. The measured data was then analysed using identification algorithms or using a MATLAB add-on – System Identification Toolbox. Some graphs of both analysing methods clearly showed that the results of both methods were almost identical - in both graphic (curve) and numerical form (the individual parameters of the transfer function). Some graphs showed different numerical results. That could be caused by the different internal pre-programmed functions of the parameter identification algorithm and also by a possible one step shift of the calculation initiation in the identification algorithm.

Fig.3 shows test results and their consequent analyses [9]. The change in the input signal was programmed in the form of a step-change and occurred at an unknown, randomly generated, time. In addition, the tested person was not told in advance the polarity of the signal. Therefore, the simple task became quite a complicated task. The pilots responded as fast as they could to an unexpected situation influenced by two important parameters – signal polarity and time of the step-change. Another important test factor is the amplitude of the joystick movement. The tested person should react adequately to the controlled system and move the joystick with an appropriate force to get maximum accuracy and to zero the gap between the actual and the required input and output signals.

<table>
<thead>
<tr>
<th>Method</th>
<th>Fit (%)</th>
<th>FPE</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifikační Algoritmus</td>
<td>91,1</td>
<td>9,1</td>
<td>0,082</td>
</tr>
<tr>
<td>System Identification Toolbox</td>
<td>94,630</td>
<td>0,00072</td>
<td>0,00072</td>
</tr>
</tbody>
</table>

Table 1 clearly shows all thirteen tests analysed using the identification algorithm method [9]. It is clear from the table that the parameter values of the pilot behaviour model transfer function are different for each individual test. The reasons were the actual physical and psychological state of the pilot, his response time, the ability to apply appropriate force to the control yoke of the regulated system, etc. Therefore, each test is unique and unrepeatable. However, the transfer function parameter values reached the same order as was theoretically predicted.

Tab. 1. Parameters of transfer function for human behaviour model calculated using an identification algorithm [9].

From these analysed results it was then possible to determine the ranges (limits) of the transfer function parameters for a human behaviour model. For the identification algorithm method, the ranges are as follows:

- $T_1 = 0.001 \div 0.042$ [s],
- $T_2 = 0.181 \div 1.779$ [s],
- $T_3 = 0.258 \div 1.998$ [s],
- $\tau = 0.350 \div 0.575$ [s],
- $|K| = 0.939 \div 1.368$ [-],
- $\sigma = 0.038 \div 0.084$ [-].

Neuromuscular time constant $T_1$ falls - for this type of test - into a very small range with order of hundredth and sometimes even thousandth of a second. Some publications [7] show range of neuromuscular time constant as 0 ÷ 0,1 s. This can be considered as a result agreement, as both tests were similar and thus comparable. In our test a reference signal and the joystick movement were watched in order to zero the gap between input and output values. In the study case [7] a car was driven, i.e. the driver was supposed to maintain the course according to the required trajectory.

Lag time constant $T_2$, related to learned stereotypes and routine habits, could not be determined with the required accuracy. As this constant is connected with routines and repeated system actions, the human responses are very automatic. This time constant should be watched over a longer time period and with a higher number of repetitive tests for each tested pilot.

Lead time constant $T_3$ represents the pilot’s ability to predict the input, i.e. to predict the oncoming situation. This constant is most noticeable when the tested person managed to reach the input signal without any unnecessary oscillations and in quite a short time. The Lead time constant lies within the range of over one second. This fact confirms the hypothesis that correct prediction and judgement of a future situation is the highest level of situation awareness. This ability can be obtained only by training and experience.

Transport delay, or human response time $\tau$, represents the delay of brain response to the pilot’s motion and visual perception. In the case study [7], the driver’s reaction time is in the range of 0,12 ÷ 0,3 s. When testing on the flight simulator, none of the tested pilots could get under the time of 0,3 seconds. This is due to the test nature and the test site layout, where the tested person was expecting a sudden change of input signal that came in unexpected time and in unexpected polarity. The only perception the pilot had, was his eye perception. That is why the range of response times is higher than in the car study case.

Pilot gain, representing pilot habits for a given type of aircraft control, lies for most tests within the range of around one. During the first tests, the pilot gain value was over one. Mainly because of the big oscillations when the tested pilots were not able to zero the gap smoothly enough and the identification algorithm could not cope with such an oscillating signal. The pilot gain depended on the tested person, i.e. on how fast the pilot could identify the change in the system dynamics and consequently respond with an appropriate force.

Standard deviation $\sigma$ is a statistical parameter showing the accuracy of the identification algorithm when creating the curve of the joystick movement. For this type of test and test site, the standard deviation is very small. This is due to the algorithm coping with the deviation between the input and output data. There were no large oscillations, as there had been when testing on the flight simulator, and therefore the identification algorithm in the form of a transfer function of the human

<table>
<thead>
<tr>
<th>Method</th>
<th>Identification Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metrics</td>
<td>Parameter values</td>
</tr>
<tr>
<td>$T_1$ [s]</td>
<td>$T_2$ [s]</td>
</tr>
<tr>
<td>1</td>
<td>0.011</td>
</tr>
<tr>
<td>2</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>0.003</td>
</tr>
<tr>
<td>4</td>
<td>0.007</td>
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<td>5</td>
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<td>10</td>
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<tr>
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<tr>
<td>12</td>
<td>0.041</td>
</tr>
<tr>
<td>13</td>
<td>0.042</td>
</tr>
</tbody>
</table>
behaviour model (1) is able to inset the joystick movement curve with high accuracy. Table 2 shows parameters of the transfer function for a human behaviour model calculated with the System Identification Toolbox. Having the same form of transfer function for the human behaviour model as was used for the identification algorithm, the data was analysed using the System Identification Toolbox. As mentioned earlier, some results were almost identical and some parameters differed. That is due to the fact that each analysis method has a different main internal function assisting the calculation.

Tab. 2. Parameters of transfer function for human behaviour model calculated with MATLAB – System Identification Toolbox [9].

<table>
<thead>
<tr>
<th>Method</th>
<th>System Identification Toolbox</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>$T_1$ [s]</td>
<td>0.001</td>
</tr>
<tr>
<td>$T_2$ [s]</td>
<td>0.030</td>
</tr>
<tr>
<td>$T_3$ [s]</td>
<td>0.001</td>
</tr>
<tr>
<td>$\tau$ [s]</td>
<td>0.300</td>
</tr>
<tr>
<td>$</td>
<td>K</td>
</tr>
<tr>
<td>$\text{Fit}$ [%]</td>
<td>82.80</td>
</tr>
</tbody>
</table>

From the table, the lowest and highest values of individual transfer function parameters were selected and the ranges were determined for the System Identification Toolbox method. The ranges are as follows:

- $T_1 = 0.001 \div 0.100$ [s],
- $T_2 = 0.030 \div 1.182$ [s],
- $T_3 = 0.001 \div 1.101$ [s],
- $\tau = 0.300 \div 0.525$ [s],
- $|K| = 0.930 \div 1.057$ [-],
- $\text{Fit} = 82.80 \div 94.81$ [%].

5 Conclusion

The point of conclusion is not to comment on individual parameters of transfer functions and their significance. That has already been done in the chapter describing the ranges of time constants for the identification algorithm method. However, it would be appropriate to comment on result differences between both methods.

The most significant difference between the two methods, for all the conducted tests, is the minor disadvantage of a pre-programmed identification algorithm. Unlike the System Identification Toolbox, the calculation start of the transfer function parameters is always shifted by one sampling period. The pre-programmed algorithm has set limits (dead zone) and as soon as the input signal enters this zone the whole program starts calculating transfer function parameters. However, this is done with one step delay which, in our case, is a sampling period of 0.05 s. This disadvantage, however, later became an advantage when testing on the flight simulator. It is the fact that the pre-programmed algorithm has an option for pre-setting limits for initiating the whole analysis process.

In conclusion, it can be confirmed that both methods for calculating transfer function parameters for a pilot behaviour model are comparable. The testing and work GUI is simple and easy. The data result form for both methods, developed by the authors as a standard, is effective and fast. Therefore, future utilisation of this test site at various air bases for testing pilot’s actual physical and physiological state and abilities is in place. As a part of further research and future testing, it would be suitable to watch and test the pilot student’s during their entire studies at the University of Defence to assess their progress in coping with the unpredictable step-change, or analyse transfer function parameter changes over a long period of time.

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References:

[4] N. Cameron, D. G. Thomson, D. J. Murray-Smith, "Pilot Modelling and Inverse Simulation for Initial Handling Qualities Assessment,” in Mathematical Methods and Optimization Techniques in Engineering


