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Development of Multifunctional, New Generation Flight Simulator and Examination of Different Control Systems

Summary of Ph.D. Thesis

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Introduction

The first flight simulator was built by Edwin Albert Link in 1929 [Nagel 1988] which he symbolically named Blue Box [Constantin 2000]. During the last more than 75 years, due to the exponential evolution of science and technology these devices have gone through a large series of technical and conceptual developments.

Today flight simulators play an important role in both theoretical and risk-free practical flight training, scientific research, and also result in extensive cost savings. It is a known fact, that a new conceptual or technical solution to be implemented in aviation can require up to 30 years, while they are being tested on simulators as well. Currently personal computers have reached such a processing speed, memory capacity, and graphical performance, that they can be used to replace the expensive graphical workstations, thus permitting the design of low-cost simulators.

The Department of Aircraft and Ships at the Budapest University of Technology and Economics applied successfully at the Ministry of Education for a tender to build a research and development flight simulator, and now following the completion, they are in possession of a new generation, PC-based device.

Goals and Summary of Thesis

About eight years ago the staff of the Department of Aircraft and Ships at the BUTE, together with the Technical University of Munich's Department of Flight Mechanics and Flight Control, decided to build a low-cost flight simulator for research and educational purposes. My tasks were initial design planning of the simulator, supervision of it's development, and proving it's usability. As the goal of my dissertation I defined and specified the equipment during initial stages of development according to the latest technological and scientific achievements, as well as I proved it's suitability for educational and research purposes. The simulator was made according to the most modern principles and meets most of the requirements of the planned educational and research tasks. One special attribute of this simulator is that on the captain's side a control column was installed, while on the co-pilot's side a sidestick. The completed fix-base simulator was among the first to utilize PC-based simulation software, using a single-channel DLP projector-based visual system, integrated touch screen liveware-hardware interface, integrated flight instrument displays (glass cockpit philosophy), and the combined use of demonstrational and research software.

In the first part of the dissertation I deal with the historical background, general review, classification, goals and advantages, and introduction of certain systems of flight simulators. I also phrase therein the goals of building the simulator, I present the purchased items and software, the building process as well as a bibliographical review of the ergonomics of the control elements. In the second part I define the goals of my measurements and I also give a summary about the principles of the electromyography and heart period variability on which the physical and mental workload measurements are based. This part also contains the description of the measurements and the evaluation of the results.

The goal of the experiments was to demonstrate the applicability of the simulator through physical and mental workload measurements with regard to the advantages and/or disadvantages of using a column yoke or a sidestick. During the experiments, the pilots had to complete different tasks. During the physical workload measurements they had to land at Budapest Ferihegy Airport, while during the mental workload experiments they had to fly two different routes with the same level of difficulty. As part of the experiments I recorded selected flight variables and compared their mean error rate statistically in order to analyze the accuracy of the execution of the tasks.

I made the physical workload measurements using a 4-channel EMG instrument. The analysis of the signals was done using the Matlab program, which consisted mostly of the analysis of the signals' center frequency. During the mental workload measurements I recorded the heart period using the ISAX system and analyzed the data using the INTERFACE system. The experiment is based on the fact that the changes in heart period variability are caused by variations in cognitive effort.

The simulator, built to fulfill the needs of both educational and research purposes, provides the Department of Aircraft and Ships with multifunctionality, flexibility, and research opportunities in aviation science and multidisciplinary fields, which they seem to be utilizing successfully.

Brief contents of the individual chapters

In the first chapter the history, general introduction, categorization, goals and advantages, system (cockpit, image generation and projection, sound generation, computer and interface, instructor control) descriptions, and basics of simulation are discussed.

Based on Korody [2000] the deduction of the equations of motion forming the flight simulation's base is presented.

A full flight simulator is composed of the following major parts: 1. simulator casing, 2. image projection system, 3. moving platform, 4. motion system, 5. fixed platform, 6. flight deck.

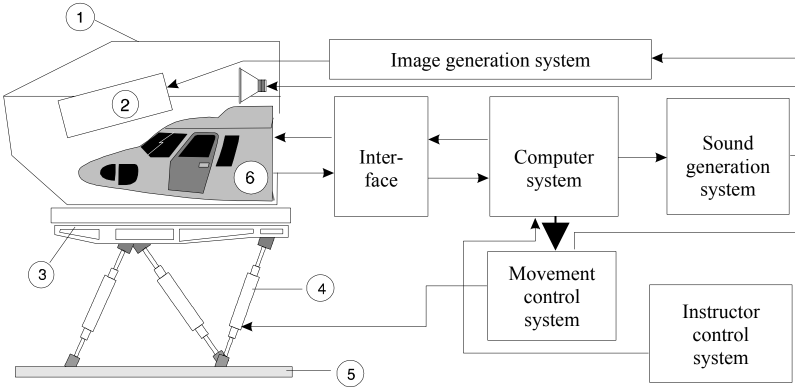

Image 1. Full flight simulator schematic
(Based on Constantin [2000], modified)

Based on international regulations, simulators possess the following advantages:

- significantly lower cost compared to practical training on actual aircraft;
- saving of various resources, including fuel, control systems, etc.;
- independency of geographical location or weather;
- self-rating possibility, in other words the ability to analyze qualifications;
- high authenticity and zero risk in solving special situations;
- flexibility with the assembly of the training program.

The 2nd chapter contains my goals, a list of most of the devices and software purchased, my report on the design and building phases of the simulator's development. Furthermore I provide herein a review of professional literature on the ergonomics of flight control systems.

Based on the three law of technologies (Moore, Gilder, and Metcalfe) [Rohács 2004], I created the structure of the simulator, which is presented on image 2.

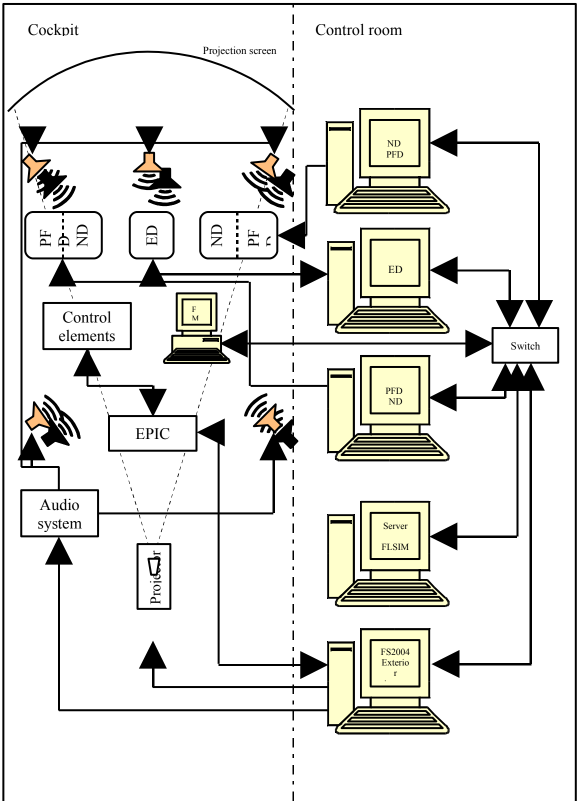

Image 2. The structure of the simulator [Korody 2002/b]

The most significant advantages of the flight simulator we created are the following:

- low development cost;
- integration of two different flight control systems;
- suitable for education, research and development;
- reconfigurable;
- editable and expandable database;

- built-in touch screen displays;
- rapidly exchangeable instrument displays thanks to the VAPS software environment;
- supports the use different software based on the purpose of application.

In the 3rd chapter, besides composing my objectives, I provide a summary about electromyography (EMG), which forms the basis of measuring physical load, the possibilities of signal processing, and also present the work involved in my experiments, and their results.

Both of my experiments were explorative studies, with revealing purposes (no previous specific hypothesis), and based on a small array of samples (6), with the aim of proving the simulator's suitability for research. A secondary objective of the measurements was to find an answer to advantages and/or disadvantages of the use of control wheels and sidesticks.

Image 3. During EMG measurement

According to William [1992], EMG is a device (analytical method) which can be very useful in ergonomic studies. Mark [1992] states, that during stationary muscle fatigue the two most notable changes in the EMG signal are the shifting of the frequency content towards the lower values, and the increase of the amplitude.

I positioned the surface electrodes on the following muscles: wrist extensor, biceps brachii, anterior deltoid, and upper trapezius. The results of the test showed different spectrums of frequency in case of some pilots during the use of the different flight controls, therefore the system is under certain circumstances suitable to compare these control techniques with regard to the amount of physical load.

The 4th chapter contains a review of the literature related to the measurement of mental effort, the description of my analysis based on heart period variability (HPV), and the evaluation of the results. The tests were concluded with the assistance of the BUTE Department of Ergonomics and Psychology.

According to Vetter [2003], the spectral analysis of heart rate (HR) or HPV is a non-invasive method, and reflects autonomous nervous system activity. It allows separation of the sympathetic and parasympathetic effects, thereby providing a look into the actual balance of the autonomous nervous system. The core of the method is that in case of healthy humans, under entirely calm conditions the HR is not steady, but shows a quasi-periodic variation. Under normal conditions, specific variations can be observed on the heart period series. Láng [2004] states also, based on several studies published during the 1960's and 70's (Kalsbeek and Ettema [1963], Luczak and Laurig [1973], Mulder and van der Meulen [1973], Rohmert et al. [1973]) that during mental effort, HPV decreases significantly especially during situations involving decision making.

Image 4. shows an example of the HPV graph during the use of the sidestick control in case of pilot nr. 3., where the lower values indicate a higher mental effort.

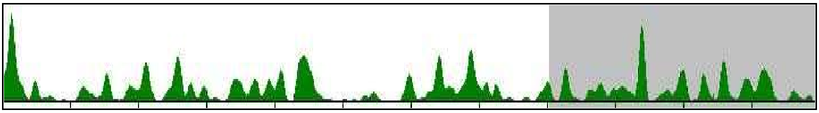

Image 4. HPV recording of pilot nr. 3 during the use of the sidestick

It is encountered also based on the measurement of mental effort, that the use of the different flight control systems produces different HPV graphs, therefore this method can be considered suitable under certain conditions to compare the two control techniques with regard to pilots' mental load.

In light of the successful building of the simulator, and the recent times since it's completion, I can conclude that the preset goals have been reached. It has been proven, that decision to support a PC-based simulator, and the use of DLP projectors was the most favorable, since this has resulted in the Department now possessing a low operation cost device, the design costs of which were also low. Concerning the installation of dual flight control systems in a single simulator, I can conclude that it was highly successful. Professional pilots who visited the simulator also praised the device.

Thesises

During my work I achieved the following new results:

1. Having examined the evolution of digital technologies, the prognosis of their changes, and the range of applicable devices (software and hardware), based on both educational and research needs, I determined the hardware and software minimum requirements, structure, and support requirements of a flight simulator device.
    1.1. I concluded that for research and educational simulators, the use of 2D visual display systems is adequate, integration of motion systems or fully authentic instruments is not required, however multifunctionality (the options to change instrument displays, aircraft flight models, terrain layouts and flight conditions, e.g. weather) and the possibility to record flight data must be provided.
    1.2. The structure of the simulator was defined.
    1.3. I concluded that the support requirements of a research and educational simulator device consists hardware-wise of PC-s responsible for individual tasks (external image generation, instrument display, flight model calculations, etc.) connected in a network, while software-wise specifically determined configurations based on the relevant educational or research goals (e.g. Microsoft Flight Simulator, FLSIM, VAPS, MATLAB, etc.), and to accommodate for other special needs (e.g. touch screen applications, different flight control systems, etc.).
2. Based on innovation theories, familiarity with technological prognosis programs, and using the laws determining technological development, I planned the new generation educational and research simulator, which was built among the first in it's kind by the employees of the department and myself.
    2.1. I achieved the low building and operation cost of the educational and research simulator by the fixed base configuration, PC-based support, the single channel 2D image projection system, and the use of software (FLSIM, VAPS) for the first time in Hungary.
    2.2. I designed the simulator to provide numerous multifunctional capabilities, flexibility, and development opportunities in the fields of both aviation science and multidisciplinar research (e.g. touch screen; integrated instrument display with VAPS quick prototype planning tool; connecting MATLAB or FLSIM based simulations with FS external view; examination of various control systems with thrust vector-driven UAV; calculation of tensions originating

from the centroplane during flight using a final-element module; etc.).

   2.3. As a peculiar characteristic of the educational and research simulator, two different flight control systems were installing in the cabin following my recommendation (a conventional control column on the left – resembling the Boeing philosophy, and a sidestick on the right – based on the Airbus solution) which provides grounds for wide range and multidisciplinary analysis of different aircraft control solutions (e.g. simultaneous ergonomic and flight technique analysis).

3. While testing the applicability of the completed educational and research simulator, I measured the physical and mental effort of pilots based on EMG (electromyography) tests during the use of the two different flight control types.

   3.1. Based on the mean frequency values of the EMG signals recorded from the muscles I concluded that physical fatigue of the pilots differs when controlling the simulator using the control wheel and the sidestick (the effect of positioning these control devices on the pilots' physical load requires further analysis).
   3.2. Based on my research, I find the method to be suitable with more strict experimental conditions to compare the resulting physical loads of using the control wheel and the sidestick.
   3.3. Based on the statistical analysis of the absolute error of flight parameters, I did not find significant differences between the use of the two different flight controls.

4. For the purpose of researching the applicability of the simulator, I analyzed the mental loads on pilots to compare the two aircraft control methods.

   4.1. Based on the heart period variability analysis I concluded that a difference can be observed in the amount of mental effort involved from the pilots during the use of the control wheel and the sidestick.
   4.2. Based on the experiments I concluded that the method is suitable for the comparison of mental load during the use of the two flight control systems under specific conditions.
   4.3. I completed the statistical analysis of absolute error values of the flight variables as well, and based on the results I did not find any significant difference between the performing ability of the pilots with either of the two control systems.

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