Simulator Technology in Optimising the Human-Automated System Interface

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SUMMARY

Increasing complexity of human-operator environment required from him higher and higher abilities in input data analysis, decision making and controlling of the object (system). Time deficit combined with above requirement caused introducing the automatic systems supporting the human-operator in his tasks performance. Effective support of the human-operator activity was also possible thanks to the technology achievements, i.e. more efficient and cheaper computer systems.

Complex, hierarchical control systems took a part of work typically done by the human-operator. After initial "computer euphoria" some problems appeared; smooth co-operation between human-operator and automatic or automated system sometimes became not very effective or even problematic. That situation had usually appeared during untypical, dangerous situation, when standard decision should have been modified and new action was required. Some mishaps or even fatalities showed that the problem existed and should be worked out. In such very complicated situation researchers and designers needed a tool for replicating the environment of human-operator, with all factors and stimuli acting on the human in the real situation. It was required for the proper designing and optimising automated systems, which had had to co-operate with the human-operator. Possibility of that replication created the research simulators and simulator technology.

On the example of research works, done with help of the flight simulators during the optimising of the new aircraft cockpit and designing the new aircraft, with all its on-board automatic and control systems, the simulator technology, will be presented. In the author opinion that technology is one of the best if not the best, allowing for real checking and optimising the human-operator – automated system interface in the modern, complicated dynamic systems.

1.0 INTRODUCTION

Extensive development of modern aviation both as in the number of flying aircraft and as in their abilities caused even more extensive and intensive development of automatic control systems introduced over there. Increasing number of air traffic participants was the reason of necessity of gaining the precision of air space control and air traffic management in that space. It was followed by increasing precision of navigation systems, both on-board and ground controlling that traffic. Modern navigation systems can

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determine the aeroplane position with precision of several meters and their aviation versions up to 1.5 meter. Also flight altitude is being defined with error less than 1%.

Increasing requirements on reliability and safety of flying caused automation of the bigger and bigger number of tasks and actions performed by the human-operator up to that time. In military aviation, the modern battlefield high requirements on speed and precision of combat tasks performance caused, that human-operator became the weakest element of the aeroplane flight control loop. One can expect that because of these reasons in the battlefield we could meet unmanned combat vehicles in the near future (see Fig. 1). The nearest ones will be controlled by the human-operator from the ground (see Fig. 2) and the next fully automatic, able to perform all the tasks totally in autonomic mode.

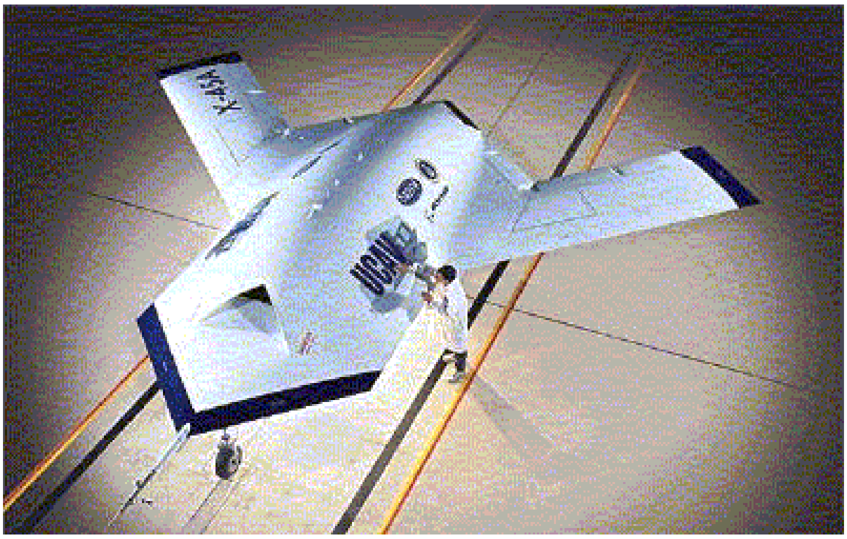

Figure 1: X-45 Unmanned Combat Aerial Vehicle.

Figure 2: X-45 UCAV Ground Control Station.

Necessity of decreasing the aircraft exploitation costs and increasing their operational reliability caused gaining the range of control functions performed by automatic systems. That range of automatic systems application and functions was increased gradually. Initially there were systems stabilising heading, altitude and velocity of flight. Next their functions were upgraded to changing above parameters according to the set values. They had had to receive basic data on the present state of controlled object. That caused their integration with navigation systems of controlled aeroplanes and helicopters. Separate systems have stabilised the power plant thrust at the value set by the pilot in automatic mode.

Increase manoeuvrability of newly design combat aeroplanes decreased their stability. Their aerodynamic characteristics substantially decreased the range of flight envelope possible to control by the pilot. In the sake of avoiding that not preferable tendency the Stability Augmentation Systems (SAS) co-operating with the human-pilot during the whole flight, have been introduced.

Development of combat systems with introducing the new versions and kinds of armament systems and new combat tasks was followed by necessity of automation of many functions, which were done before by the human-pilot or human–armament operator. Increased complexity of combat task was the reason that during target acquiring and firing pilot was unable to control effectively the aeroplane flight; that was done just as side action, almost as reflex. It was then natural to introduce automatic system taking over the aeroplane flight control during the typical flight states.

These trends have led to the situation, where almost all the on-board systems in certain flight states in the whole or in biggest part were controlled automatically. Then the problem of synchronisation and their proper co-operation has appeared. The result of that situation was introducing automatic control system, which has to control the other automatic control systems. Such superior systems are called Flight Management Systems (FMS). They are integrators of lower level on board automatic control systems. The FMS-s have whole the task to be performed stored in their memories, e.g. final destination, way of target attacking. The example structure of such aeroplane hierarchical automatic flight control system together with its environment is presented in the Fig. 3.

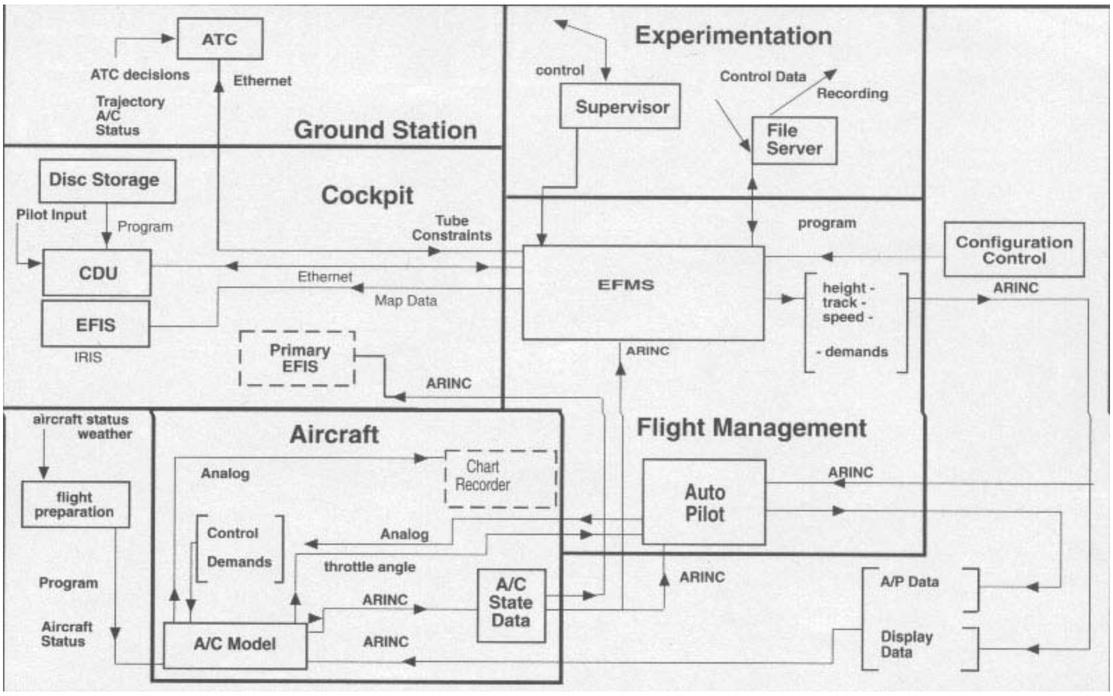

Figure 3: Experimental FMS of Aircraft with its Environment [1].

Human-operator functions in such systems are limited to control the most important task at each of the moment of flight or to choose the proper mode or parameters of FMS work. Human-pilot is always able to take over direct control of any function or system in the case of unpredicted danger or disturbances destabilising controlled aircraft out of the acceptable range of flight (result of atmosphere or other air traffic participant action). In these cases control of certain function has semiautomatic or manual mode. But in both cases control systems should be design in the way, which allows human-operator to fulfil the designated task.

As the examples of the simulator technology application in the Man Machine Interface (MMI) optimisation the designing of the following objects will be presented:

- new combat helicopter control systems,
- new cockpit of the upgraded combat aeroplane.

2.0 NEW OBJECT DESIGNING

In the process of designing the new combat helicopter the research simulator shown in the Fig. 4 has been used.

Figure 4: Research Simulator Applied for Designing the New Combat Helicopter [2].

Its crew consists of two persons: pilot and armament systems operator. That research simulator as it can be seen in the picture, doesn't replicate designed helicopter cockpit architecture but only generally presents locations of control systems elements in both cabins. Also both crew member locations do not represent the real ones. It hasn't got any substantial importance because crews participated in that research didn't train helicopter operation but test its control systems functionality and effectiveness.

Aerodynamic and dynamic characteristics of the new helicopter were calculated and designed out of the research simulator, with the use of other computer systems. Next basing on them mathematical models of flight dynamics were formulated. They were introduced into the simulator for testing their correctness and possibility of co-operation with the crew. That research flight simulator was also used as a pre-flight testing device for evaluation the newly designed helicopter by the test pilots. Negative opinion on the tested helicopter caused the changes introduced into the design. That process was repeated until receiving acceptable design solution. The most effective part of that design process was designing of the crew cockpit. The architecture of each member of the crew cabin was optimised with the use of that research simulator. Simulator technology allowed for checking many different cockpit architecture versions and choosing the best for operation in normal, abnormal and emergency conditions. Particularly the last two ones were possible only with the use of research simulator. Modelling of abnormal and emergency conditions, and presenting them to the crew in the virtual environment allowed for testing the whole system, helicopter and its crew, in the situations and conditions the most similar to the real ones, which could be met in the real world operations.

During that research many changes in layout of controlling and indicating elements have been done. Also the ways and methods of information presentation into the crew were tested. That's why the cabins have the shape of frame, to which was easy to introduce the new tested equipment. Moreover, standard transmission lines were applied for data transmission, but their number and transfer abilities were much higher than necessary. That redundancy made possible easy modifications of mounted equipment types and precise control of transmitted signals. Applied mathematical models of automatic control systems described dynamics of designed systems with accuracy up to the level of modules or elements, which could be replaced during that phase of the designing process. Combining the proper modules the description of all designed systems functioning in normal and abnormal conditions had been achieved. There were done also tests of real elements of the equipment. Some modules were mounted into the simulator cockpit for testing their integrity and co-operation with the other subsystems and elements. But designed helicopter on-board systems were tested and evaluated mostly with the use of their mathematical models.

The final result of above tests and research was the new combat helicopter "Comanche".

3.0 DESIGNING THE UPGRADED COCKPIT

The main goal of that project was the new cockpit for upgraded (MLU – Mid Life Upgrading) version of the combat aeroplane F-16 E/F. The final stage of the design and test works has been performed on the research flight simulator (see Fig. 5, 6, 7) located at NLR facility [3,4].

Figure 5: NLR Research Flight Simulator [3,4].

Figure 6: F-16 MLU Cockpit Optimised in NLR Research Simulator.

Figure 7: F-16 MLU Cockpit Optimised in NLR Research Simulator.

Research works have been conducted on the newly designed aeroplane cockpit version built on top of the simulator motion base, replacing original simulator cockpit. Other modules of the simulator: motion system, visualisation system, instructor-researcher station, computer system were used for that project purposes. The range of research was smaller than in the previous example. New cockpit and control systems were designed outside of the simulator and initially tested with the use of other methods. Research done on the simulator goal was optimising the new cockpit from the human factor point of view. So, systems were modelled up to the subsystems level and layout of the cockpit equipment was analysed. In fact, some layouts initially chosen before these tests were evaluated in the conditions of simulated environment and missions very similar to the real ones. Missions tested with the use of simulator were limited to the standard for that aeroplane.

Applied here mathematical models of automatic control systems have described their structures and dynamics of work in normal and abnormal conditions. They were created for the optimisation of their co-operation with human-operator. There were done research of ways of information presentation in different stages of flight and different missions and different conditions of mission performance. In these cases very important was accurate modelling of information transmission and its dynamics, and moreover time sequences of data transmission between all on-board systems co-operating with the aeroplane crew. Also important factor was optimisation of information sharing between crewmembers; some information should be redundantly repeated at each cockpit for the cases of emergency states of flight. Virtual environment created in the research flight simulator allowed for effective and accurate optimisation of above mentioned tasks.

Other important difference of that project in comparison to the first one presented in the paper was well known and described object of control, i.e. F-16 aeroplane. So, the mathematical model of controlled object was “stiff”, unchangeable element of the research. Then, optimisation was limited to the structure and dynamics of newly introduced control systems, and also layout of cockpit. No changes were possible to introduce into the aeroplane structure even they would be preferable from the research results point of view.

4.0 GENERAL REMARKS

Computer Aided Design (CAD) systems are becoming more and more popular in many technology disciplines. Designing new aeroplanes and helicopters with the use of computers became the standard method in the modern high technology companies. Paperless designing office, where new object appears and is developed totally in the virtual 3dimensional space, is becoming typical not only for high technology products. That way of designing and developing new products is very effective and allows for creating optimal objects. That “mechanical” attitude towards designing, which proved its effectiveness in designing practice, was also implemented or rather applied in designing of Automatic Control Systems (ACS). Initially ACS used in aviation technology next very quick that attitude moved into the other areas also.

During the process of increasing abilities of CAD systems and simplifying the work of designers, the special data bases were created. They contained not only symbols of ACS elements but also their mathematical models. Thanks to that, when designer chose an element and implemented it into the designed system, immediately mathematical model of that system was created in the background. After completing the “graphical” design designer can get on-line result of stability checking of that ACS, which is the basic procedure applied there. That easiness of checking the characteristics of designed ACS allows for quick and effective testing of many solutions and at the end for obtaining optimal ACS. Combining such designed subsystem with others and creating in that way more complicated ACS one can obtain optimal complicated ACS, for example Flight Management Control System. That technique allows for testing newly designed ACS not only in normal but also abnormal states of work. They can reflect the real emergency and dangerous situation, which could take place in the real life. And that attitude towards designing new systems came directly from the simulators and simulator technology.

Research and designing simulators allow for detail replication of human-operator work environment. Proper replicating of its dynamics is particularly important for designing of dynamic systems, and among them ACS. In these simulators one can replicate very realistically stimuli acting on the human-operator in many different states of the whole systems, and check the effectiveness of the system control by that operator. **These kinds of tests cannot be performed effectively in any other manner.** Particularly effective research simulators are for designing and testing new systems in emergency and abnormal states of their work.

Research works done with the help of simulators are very effective also in Human Factor and Aviation Medicine areas. As examples of such works and devices used for them, we can take the following systems used by the Polish Air Force Institute of Aviation Medicine in Warsaw (Fig. 8, 9, 10, 11).

Research flight simulator “Japetus” shown in the Fig. 8 is equipped with systems for medical and physiological tests and measurements, like: ECG, ECC, oculograph, heart rate, skin resistance, etc., integrated with simulator operating system [5,7,8,9]. It is being applied for aviation medicine research works and as a device used for selection of candidates to military pilot academy [6].

Figure 8: "Japetus" Research Flight Simulator at Polish Air Force Institute of Aviation Medicine.

Device shown in the Fig. 9 is being used not only for research but also for presentation and training military pilots in disorientation during the flight. It is equipped with fiberoptic transmission lines allowing for introducing any measuring equipment into the test during the simulated flights.

Figure 9: "Gyro IPT" Disorientation Training Device at Polish Air Force Institute of Aviation Medicine.

Human centrifuge presented in the Fig. 10 is dynamic acceleration simulator used not only for training pilots but also for medical research and avionics equipment testing.

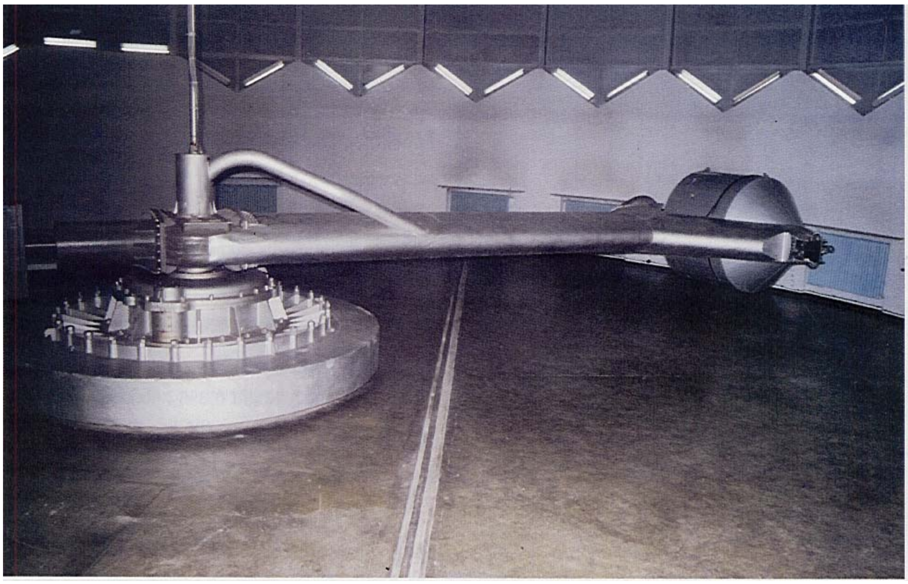

Figure 10: Human Centrifuge at Polish Air Force Institute of Aviation Medicine.

Hypobaric chamber shown in the Fig. 11 allowed for training military pilots and accustoming them for low pressure environment but also for testing equipment supporting military pilot operations.

Figure 11: One of the Hypobaric Chambers at Polish Air Force Institute of Aviation Medicine.

Presented above devices are in fact simulators of different phenomena and parameters connected with military pilots work environment. Some of them were also used for designing and testing of aircraft equipment purposes. Conditions and parameters of environment assured by them allowed for making many researches and tests from aviation medicine, Human Factor and avionics areas. These examples show in short the possible applications of simulators and simulator technology in above-mentioned areas.

5.0 CONCLUSIONS

1) Research and development simulators became important tools for designing new dynamic systems co-operating with the human-operators.

2) Main area of simulator and simulator technology application is designing the new and optimising existing:

   a) control systems (automatic and semiautomatic),

   b) man-machine interfaces.

3) In some areas, like civil and military aircraft and rocket designing, research simulator is standard tool for design optimisation.

4) Results obtained during aerospace and military projects can be transferred into other areas, e.g. designing of: land vehicles operator stands, car interiors, industry facilities operator stands, etc.

6.0 REFERENCES

[1] S. Coyle: *European ATC Experiments.* In: Avionics, September 1993, pp. 44-49.

[2] C. Szczepański: *Symulatory lotu śmigłowców.* Prace Instytutu Lotnictwa, nr 153-154, Warsaw 2001, pp. 37-43. (in Polish. *Helicopter Flight Simulators.* Proceedings of Aviation Institute).

[3] NLR: Internet Web page: www.nlr.nl/public/facilities/f164-01/.

[4] H.A.J.M. Offerman: *Full Mission Simulator for Research and Development.* International Training and Equipment Conference, ITEC'95 Proceedings, den Haag 1995, pp. 377-387.

[5] S. Barański, J. Kossowski, K. Kwarecki, F. Skibniewski, C. Szczepański: *System of Evaluating Pilot's Psycho-Physiological Parameters during Test on a Flight Simulator*. 41 International Congress of Aviation and Space Medicine, Hamburg 1993, pp. 9. Proceedings – Moduzzi Editore Bologna.

[6] K. Kwarecki, F. Skibniewski, J. Kossowski, C. Szczepański: *Full Mission Simulator Application in Polish Air Force Pilot Candidates Selection*. International Congress of Aviation and Space Medicine. New Delhi 1994.

[7] C. Szczepański, F.W. Skibniewski, M. Gąsik, O. Truszczyński: *Standard Flight Simulator as a Spatial Disorientation Training Device.* Proceedings of AIAA Modeling and Simulation Technologies Conference, Denver CO 14-17.08.2000, AIAA-2000-4077, pp. 9.

[8] C. Szczepański: *Research-Training Full Mission Simulator*. Internartional Conference "Aircraft Flight Safety" AGARD-CAGI, Moscow 31.08-5.09.1993, pp. 20.

[9] K. Klukowski, K. Mazurek, M. Gąsik, O.E. Truszczyński, C. Szczepański: *The Use of Flight Simulator for Spatial Orientation Investigation and Training.* 48 ICASM, Rio de Janeiro 17-21.09.2000, pp. 29.

[10] C. Szczepański, D. Leland: *Move or Not to Move? Continuous Question.* Proceedings of AIAA Modeling and Simulation Technologies Conference, Denver CO, USA 14-17.08.2000, AIAA-2000-4297, pp. 11.