DIAGNOSTICS OF FLY-BY-WIRE CONTROL SYSTEM

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Abstract. The paper describes the diagnostics of a fly-by-wire control system taken during the creation of this system. Special attention is paid to laboratory tests, which should prove the system could be tested in-flight. An important kind of verification of the system is testing and reconfiguring fault detection and localization methods. The human factor is also taken into consideration.

Keywords: fly-by-wire control system, tests, human factor.

1. Introduction

The design, manufacture, and start-up of complex control systems are connected with the execution of a series of tests to verify individual assumptions and solutions. By dividing the realization of a system into stages, we can distinguish diagnostic methods typical of a given stage [4]. In the case of aviation control and navigation systems, this division of diagnostic methods, including their short description, was the subject of several earlier presentations describing the experience acquired by employees of the Avionics and Controls Department of Rzeszów University of Technology [2, 3, 5, 6]. These studies did not emphasize the fact that the diagnosed system contains diagnostic procedures that can change the method of its functioning by its reconfiguration. The process of fault detection and localisation with the operator influence on this system is both a very difficult and interesting area of studies.

2. General architecture of aircraft indirect control system

Taking into account the counteraction to damages and the influence of a pilot on the aircraft indirect control system [7, 8], the general equipment architecture presented in figure 1 was accepted.
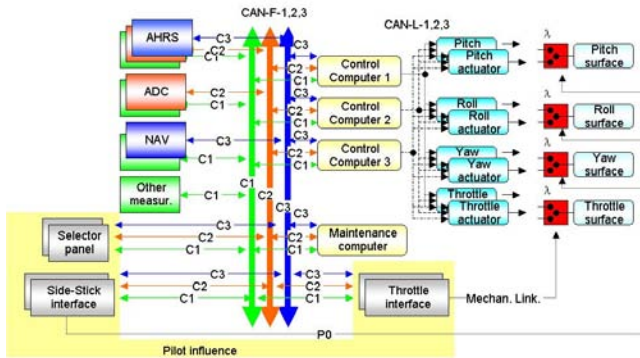

Fig 1. General architecture of the indirect control system of an aircraft, highlighting the area of a pilot's influence

The general architecture of the system, especially in case of the malfunction of an individual component, assumes that the principle of human-centred automation will be applied [7]. The system adapts itself after detecting a failure, but the pilot takes the responsibility for the safety of the flight. As is visible in the diagram shown, the system consists mainly of microprocessor units connected to multiple CAN buses according to the CAN aerospace standard. There is hardware multiplication (control computers, Attitude Heading and Reference Systems – AHRS, Air Data Computers – ADC, servo-mechanisms, pilot interfaces or CAN digital data buses — Fig. 1) and multiplication obtained by the execution of analytical calculations performed by the system. In practice, every unit of the system includes diagnostic procedures. The system software and architecture determines the functioning of these components and the entire system. So now, diagnoses already begin at the stage of designing individual components.

3. System diagnoses

The diagnoses of the system are provided by methods that are mainly selected according to the task being checked, but also on the kind of unit verified. As has already been indicated above, the system has mainly microprocessor components. The basis of all further work is to create error-free microprocessor components.

3.1. Diagnostics of microprocessor systems

When creating a microprocessor system, it is already possible at the stage of designing its hardware and software to detect errors that could be significant to system functioning. The use of computer systems accelerating the process of microprocessor design by simulations used to verify the design – CAS/CAV (*Computer-Aided Simulation, Computer-Aided Verification*) – removes these

errors to a considerable degree. While creating such a control system, both equipment and software come into being, as opposed to many research centres concentrating frequently on creating very sophisticated algorithms, and using only off-the-shelf equipment modules. This provides the possibility to obtain thorough utilization of the resources of the system for realized tasks. With this approach, it is fully possible to make good use of the hierarchical interrupt structures, event handling, or hardware-software verification of the correctness of system functioning. Asynchronous actions can however begin to appear, and the diagnosis of such actions, even when using specialized start-up devices, can generate some problems. Faults in the equipment and software may arise. Very often, some forgotten methods may be helpful in finding these types of faults: the use of address traps, analysis of input/output data structures, or even modification of the system in order to obtain access to asynchronous signals of the system [1]. However, the most difficult for detection and removal are the faults arising at the full load of the system, when the additional interaction of events resulting in the fault occurs. These mistakes often appear only during the integration of the system, when asynchronous interactions occurring between individual units are activated.

3.2. Laboratory test stand

To have test results as reliable as possible, the tests have to be made in conditions as near as possible to the conditions occurring during normal operation of the system. For this purpose, a special laboratory test stand based on the method "hardware-in-loop simulation" was designed and made [2]. The creation of conditions for carrying out tests as near as possible to the "real operating conditions" of a tested device and system operator, if his interference was taken into account, was the basic task laid down for this stand. One may carry out tests on particular modules of a system and check operation of a complete control system. These stands were made by using PC-class microcomputers with add-on devices (e.g.: laboratory version of CAN data bus, flight parameter and control system status visualization system, movable platform for testing reference systems, etc.). The jobs of distributing tasks between the computers, assigning the preparation of tests (simulated models, stand configuration, etc.), and supervising the test carried out (interference of test operator) were given to one of these computers. The second computer was responsible for real-time execution of the simulation models prepared. The third computer realized the acquisition and recording of the data and communication of the system operator with real-time system units. Specialized input-output cards were installed in particular computers. When testing system integration, the stand was configured as shown on figure 2.

On-board computers, on which the software to realize earlier tested control laws was installed (Item 1, Fig 2), were connected into a simulation loop, "hardware-in-loop simulation" (Item 2 and 3, Fig 2). The on-board computers may co-operate with real or simulated board

instruments. The parameters measuring units that define angular orientation of the aircraft (AHRS – Fig 1) may be installed on the movable platform. Thanks to the specialized equipment of the computer simulating the behaviour of real systems, (Item 4, Fig 2); it is possible to connect the tested object the same way it would be in an aircraft. The pilot/operator of the system (Item 5, Fig 2) controls the simulated aircraft model using real control computers (Item 1, Fig 2). The values of aircraft flight parameters are transferred from simulated sensors to the system (Item 3, Fig 2) the same way as in an aircraft. Depending on the simulating task being realized, the data collection blocks are changed and a model of the control systems being tested may be introduced. The software was made using Visual Basic and Visual C ++ software. Because MATLAB with Simulink was used for earlier research, it was used to create the module software of the stand. There is clear to observe and modify relationship between environment, test stand and software of real systems (Fig 3).
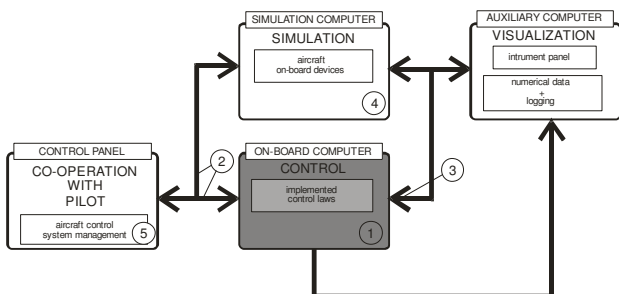

Fig 2. Diagram of stand configuration purposed for testing control systems
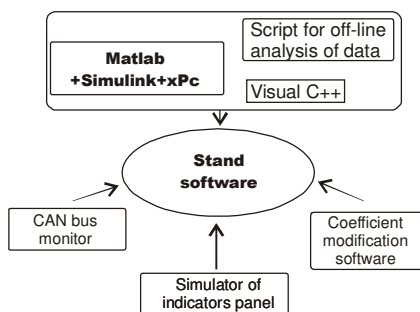

Fig 3. Diagram of laboratory stand software

It was assumed that the means of presenting information to the pilot during tests would display the test aircraft flight parameters as near as possible to the method of presenting real aircraft flight parameters. Using a graphical instrument panel with a set of flight indicators did this. This panel contains artificial horizon, speedometer, variometer, altimeter, and propeller speed indicator. It was decided to present navigational parameters using a solution based on the air map used during earlier studies of the control system of unmanned aerial vehicles [2]. The air route, with icons that allow one to determine the course, geographical location co-ordinates of the aircraft and selected ground objects (e.g. the airport), is shown on the background of the air map of the region. The visualization of the flight parameters and

diagnostic information of the tested system that are required to execute the test programme are presented enabling quick identification and modification of parameters (Fig 4). The software used for visualizing aircraft flight parameters and carrying out tests was also used for work done on a real aircraft and during test flights.
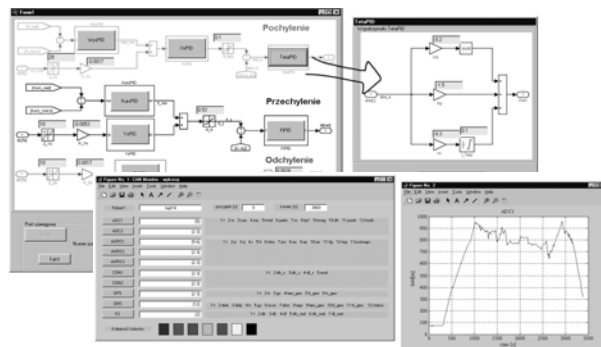

Fig 4. Examples of visualization of laboratory tests

3.3. Laboratory tests

While performing tests, one encounters two types of tasks: detecting faults in real units of a system and testing system operation after a failure. Simulating the failure of one of the modules does the second type of testing. The laboratory tests related to the functioning of devices without the participation of a pilot and in case of a failure allowed the diagnostic process and reconfiguration parameters realized by a specific device to be determined. For example, this was used to determine maximum permissible deviations of servo-mechanism control signals generated by control computers, time delays of initiating failure detection purposed to eliminate false alarms for component handshaking processes, etc. The tests conducted with the participation of a pilot deserve special attention. To examine objectively pilot's workload during particular tests, the criterion of quality J, the value of which depends on the number and amplitude of movements made with the flying controls, was introduced:

$$J = \frac{n\sum\limits_{i=1}^{n}M_i}{t_c}$$

where: n – number of movements, M_i – amplitude of i-th movement, and t_c – time of monitoring.

Before starting the tests with the participation of a pilot, the pilot was ordered to make exactly defined manoeuvres. While the flight was taking place, a selected, an unexpected failure was simulated and the control process with the counteracting system activated was examined. For example, when ordering the pilot flying at constant altitude after failures in the pitch rate measuring circuit (which results in the incorrect functioning of the pitch damper) appear, the control results are presented in figure 5.

The reconfiguration of the control system results in a distinct decrease in the coefficient of the pilot's workload from the value of 52 to 27 %/s Other parameters, like the

average amplitude of movements or the number of movements made by the pilot within a time unit also change. In both cases however, the parameters of flight stabilization such as altitude error and standard deviations of altitude have similar values (altitude error ≈ 1.5 [m/s], standard deviation ≈ 1.4 [m]). System parameters and system reconfigurations rejected as too burdensome for the pilot (monitoring the workload indicators and taking into account a survey conducted with the pilot) were selected when conducting many tests with the participation of few pilots. In-flight tests were started after positive results for all laboratory tests were obtained.
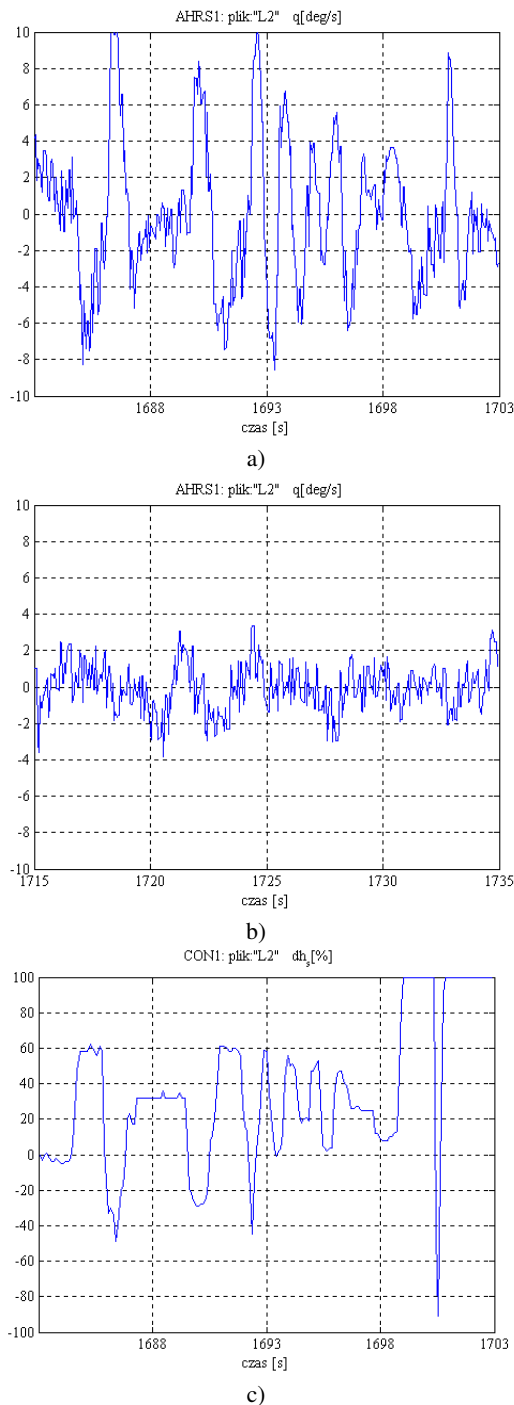

a)

b)

c)

d)

Fig 5. Selected flight parameters with q measurement defect when stabilizing flight altitude; left side – before reconfiguration, right side – after reconfiguration; a), b) pitch rate changes q [°/s], c), d) movements of flying controls

3.4. Preparation for in-flight tests

The in-flight tests were the last stage of research work on a control system modifying the handling proprieties of a general-purpose aircraft. These tests are to be conducted with the PZL-110 "Koliber" aircraft fulfilling the function of an experimental aircraft. During the in-flight tests, a pilot supervising the flight of the aircraft and a system operator conducting the tests will be on board. To do the tests, a lot of mechanical and electrical modifications of an indirect control system were made (Fig 6).
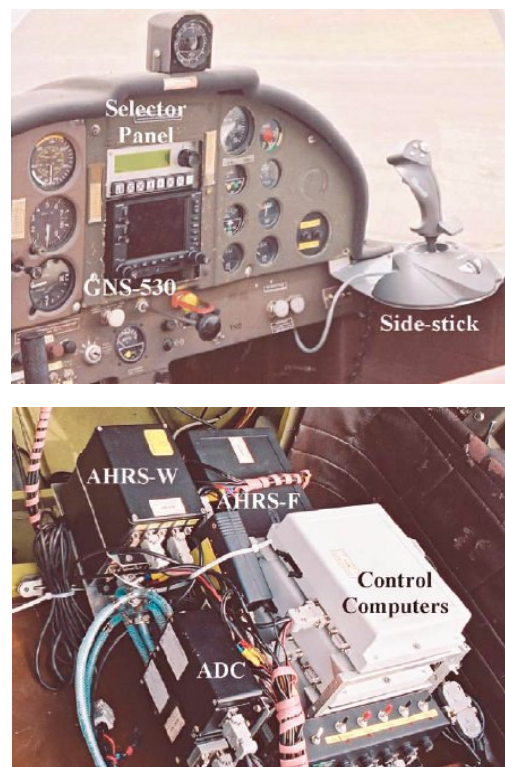

Fig 6. View of control desk and elements of indirect control system installed in the PZL-110 "Koliber" aircraft

Ground tests of the completely prepared control system were conducted before executing the first flights. Tests were conducted to verify correct operation and indications of measuring systems and communication systems and the operation of servomechanisms and data acquisition and logging systems. The realization of the function of synchronizing initial values of control signals and correct switching and functioning of control modes at no-failure and emergency conditions were checked. At all stages of flight preparation, a computer designated for to acquire and log flight parameters during laboratory tests was used. In-flight tests to document the correct operation of the control system are now being conducted.

4. Conclusions

Testing designed control systems comprises a series of various diagnostic methods that assure the creation of fault-free systems. One has to remember that complete elimination of faults is not possible, but we try to minimize their effects by multiplication and reconfiguration. The control system presented is very interesting because it goes between the object (aircraft) and pilot. It has to help the pilot to carry out the aircraft control process that may be measured quantitatively according to the method specified in this paper. It allows assumed methods of control used after a failure of a system component to be verified. The methodology of research work that is presented is the objective but it takes into consideration only the behavioural aspect of a pilot's activities. This methodology should be also competed by cognitive analysis of pilot's decision process. The analysis of these activities will allow the pilot-control system relationship to be understood more deeply and may help to develop a pilot decision aid system that would assist the decision-making process in emergency situations.

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KOMPIUTERIU REGULIUOJAMOS VALDYMO SISTEMOS DIAGNOSTIKA

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S a n t r a u k a

Straipsnyje apibūdinama kompiuteriu reguliuojamos valdymo sistemos diagnostika šios sistemos kūrimo metu. Ypatingas dėmesys skirtas laboratoriniams bandymams, kurių rezultatai turi būti patikrinti skrydžio metu. Vienas svarbiausių sistemos verifikavimo būdų yra gedimų nustatymo ir lokalizavimo metodų bandymas. Taip pat įvertinamas ir žmogiškasis faktorius.

Reikšminiai žodžiai: kompiuteriu reguliuojama valdymo sistema, bandymai, žmogiškasis faktorius.