

## THE LABORATORY STAND INTENDED TO TEST AND PROTOTYPE CONTROL SYSTEM FOR SMALL TRANSPORTATION AIRCRAFT

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***Abstract:** The paper presents a conception and a practical realization of the laboratory stand intended to perform basic and advanced tests of the control system for small transportation aircraft.*

*The stand is made with use of Matlab and Simulink environment. Using xPC and RTW modules enables the system to do some tests in real time with "Hardware in the loop" including tests with pilots. As a hardware there was used PC computer equipped with specialized boards, including A/C, C/A, converters and RS232, LPT, CAN 2B data lines.*

*The main task of the presented stand is to make possible testing of control system introducing unconventional conceptions of aircraft controlling (e.g. smart control and decoupled control techniques).*

***Key words:** control system, small transportation aircraft.*

### 1. INTRODUCTION

During a few last months Avionics and Control Department of Rzeszow Technical University works with a project of smart control system intended for small transportation aircraft. The main goals of its activity are to test new control algorithms during real flight. It is evident, that such responsible and influencing people's safety device must pass lots of tests before it can be exploited on aircraft's board. Then it is necessary to perform varied tests in laboratory conditions to give an answer for questions related to its reliability and safety. If conditions of performed tests are maximally similar to normal operational conditions, received results are more accurate and reliable. For above-mentioned reasons, to execute all required tests a special laboratory stand was made.

### 2. GENERAL CONCEPTION OF THE CONTROL SYSTEM

The main assumption in a project of new control system for small general aviation aircraft is the system made in Fly-by-Wire technology. There is not direct mechanical, but only electrical connection between control devices (stick, control wheel) and control surfaces. Additionally in proposed solution there is no direct proportional transition from the stick's position to position of control surfaces. Pilot using control devices (stick, sidestick) demands only parameters of flight. They are sent to the main on-board computer where control signals for actuators moving control surfaces, are prepared. In a such solution it is possible to give to control device's movement pure functions controlling airplane's space attitude. Such conception of control system is called as decoupled.

According to the foregoing assumptions, an aircraft equipped with such control system, is driven by automatics all time. The pilot's role is only to assign aircraft's flight parameters.

Suggested conception of the control system allows:

- to stabilize flight's parameters automatically and to minimize disturbance's influence,
  - to modify airplane's flight properties,
  - to use mechanisms protecting airplane to dangerous situations or abnormal states of flight.
- Both the general structure and properties of digital indirect control system were presented in works [6,7,8].

### 3. THE STRUCTURE OF THE LABORATORY STAND

The process of prototyping and testing of complete control system likewise its separated elements was run on specially prepared laboratory stand. It was guided according to "hardware in the loop" methodology. The tested system or its component is connected to peripheral instruments simulating all devices, which are normally cooperating with it. All signals incoming to and outgoing from the tested object are that same as signals in real operational conditions. Such solution leads to the situation, when tests can be performed in terms maximally similar to "real world". It can be said, the tested object "feels" laboratory equipment like cooperating instruments in conditions of destination. All of them cause that results of the tests are more reliable and make possible to predict accurately behavior of the tested object during future work.

Using experience reached during earlier work with a laboratory stand (testing a control system for unmanned flying vehicles [1,2] and other activity of Avionics and Control Department) it was decided to give to the stand following structure (fig.1).

The described laboratory stand consists of three basic elements, including – two PC computers and set of several additional peripheral devices needed to perform tests and prototyping processes. All of them are linked each to other via following data buses: CAN-2B, RS-232 and Ethernet network.

Software of the stand consists of following elements: Matlab + Simulink (R12), MS Visual Studio (v. 5.0), user-created specialized software and Windows 2000 operating system (only PC No 1).

The computer PC numbered as "1"(fig. 1) realizes three main functions. The first, at initial period it enables to create and compile model running in real time on the second PC. Later, when simulation is running, it can control that

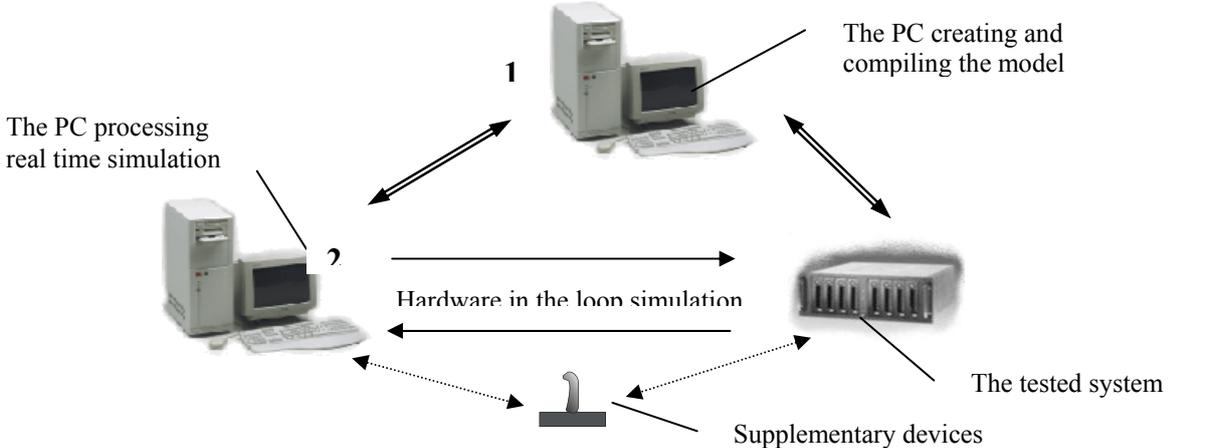


Figure 1. Schematic of laboratory stand's structure.

process and gives access to all coefficients of simulated model, allowing to on-line modify their values.

The second task of that PC is CAN data bus monitoring and communication with devices connected to it. All parameters from data frames are collected, into groups related to devices they come from, and presented in both digital and graphical form. Also, it is possible to send special data frames to simulated and real devices controlling their work.

The third goal is visualization of state of the simulated aircraft model. Although Matlab's software enables tracing values of all parameters appearing in model's structure yet it is possible only in digital or chart form. Such way of presentation, even for advanced researchers, can be troublesome to imagine space orientation of aircraft and almost quite makes impossible to manually control the model. So, there was written software presenting flight parameters of the simulated aircraft in form similar to cockpit arrangement. As a supplement of visualization process, data acquisition can be treated. Selected parameters describing work of the tested object and testing devices are recorded and kept for posterior investigation.

The main task of the PC numbered as "2" (fig. 1) is to process simulation of all models prepared on the PC No. 1. A completed, compiled, model is downloaded, via Ethernet network, and executed under specialized Matlab's operating system. The simulation process also can be controlled from that PC and access, on-line, to model's coefficients is enabled.

Processes of testing and prototyping require running communication with several external devices via various interfaces: CAN 2B, RS 232, analog and digital signals. Foregoing reasons effected, PC was equipped with several boards enabling that process. Boards selected to be mounted into that PC had to meet two criterions: functionality – must enable realization assumed tasks, compatibility – must be supported by Matlab's xPC module.

The third component of stand is a set of supplementary devices, which are necessary to proper work of completed system. They are mostly used for communication between operator and system. The first of them is a specially prepared joystick, realizing function of the stick from real airplane. It means, is used to control the simulated model of plane. The second device is a control pulpit, having function of autopilot's control console, controlling work of the simulated control system. The last device from that set is a display used by system to generate messages intended for operator.

It must be mentioned that the main task of the projected control system, what is to facilitate work of pilot, is planed to be reached by introducing control laws, which modify handling qualities of plane. For foregoing reason, tests performed with the stand have not only to check if both hardware and software work correctly but also have to check functional side of implemented control algorithms. Handling qualities influence pilots feelings, then, it is impossible to completely rate their work, and functionality, only analyzing graphs and recorded data. To reach complete grade about them it is necessary to consider pilot's opinions. For that reason stand's structure should enable to perform test with pilots. General conception tells that the stand should be prepared similarly to a simple flight simulator. The airplane model is controlled via tested control system by external control devices (stick, mini-stick or joystick). Results of simulation, aircraft space orientation and flight's parameters, are presented in shape of gauges in airplane's cockpit.

#### **4. MODES OF WORK**

Going to realize the main task of laboratory stand, performing maximal number various tests of completed system and its separate elements, its structure enables work in two main modes. Each of them realizes various tasks and makes possible to perform various tests.

1. That mod of work was used to test the general conception of control system it's structure and algorithms of control. The most characteristic attribute of that mode is, that almost all components of control system are virtual. Airplane's dynamics, behavior of measuring devices and actuators, and work of main computer's algorithms are simulated. Only one component of system is real element, it is pilot's console. It can be said that airplane's model is stabilized by simulated control system and only manually controlled using stick, joystick, steering wheel connected to PC No. 2 via CAN or analog interface.
2. That mode makes possible to test work of real devices being elements of projected control system, including its software and hardware. Intending to test a functional side of real devices (main computer, actuator) it is necessary to introduce such device into structure of testing stand. And it is the main feature of this mode. Real devices are introduced into structure of the stand in place their models and cooperate with simulated models of the rest of the system.

## 5. MODELS

All models are prepared in Matlab and Simulink environment. Working with that software, model is created and evaluated using graphical interface supported by specialized programming language. The model is mainly constructed, using ready-to-use, presented in graphical form, standard dynamical and algebraic blocks likewise connections between them. For more complex and untypical components of the model it is easier, and sometimes necessary, to introduce blocks of s-function type, which are programmed in Matlab's scripts (so called m-files). Unfortunately standard m-files doesn't work with real time Matlab's libraries. So all s-functions, intended to be used in real time simulations, must be written in C++ programming language and compiled with C++ compiler as so-called mex-files. Completed system is translated to C++ and compiled, with one of selected compilers, to a file witch can be executed with specialized Matlab's operating system.

Models for tests are created according to two main assumptions. Because of great variety performed test, it was assumed that both control system and airplane models should have modular structure. Going to close imitation of real system into model, next assumption was, that logical and functional structure of control system model and airplane model should be that same like structure of real objects. Then studying the structure of completed control system model, following main functional blocks can be pointed: aircraft (including engine, atmosphere), actuators, on-board instruments (including CAN interfaces) and module of the main computer. Above mentioned assumptions make possible, that some kinds of changes in model's structure make no large problem. Such operations as exchanging control laws, replacement one actuator model by another, introducing new elements or removing useless blocks, are reduced to few simple actions. And they can be made in graphical environment of Simulink. User-created libraries contain sets of actuator models, structures of control algorithms and aircraft models. They were partly prepared at the beginning of works with the stand and were being developed during next test and researches.

## 6. TESTS

The process of testing performed using described stand was split into two groups of tests. The first of them consists of tests going to check and verify work of separated components of projected control system. And it more concerns hardware and software side of devices then either control laws or control algorithms implemented to the main computer.

That part will be finished with tests, which will verify hardware cooperation between all components in completed system.

The second part of researchers refers to functional side of projected control system. During it, various conceptions of aircraft controls are implemented [3,4,5], tested and rated. Examined control algorithms often modify aircraft handling qualities. Because of it this part of researches includes also tests with pilots. The testing process of control law goes in two following steps.

1. Pilot controls airplane model via simulated control system, during that process he can, at will, control aircraft's space orientation. And his goal is to describe aircraft's behavior (similarly like for Cooper-Harper rate) using one of four grades (excellent, good, poor, unacceptable). The grade unacceptable doesn't admit the algorithm to the second step.
2. Pilot accomplishes the test, controlling plane to follow orders generated by system. The grade of plane's behavior consists of following parts: - pilot's opinion about plane's qualities during exercise (grades like in previous point), - analysis of errors between desired and real flight trajectory, - analysis of pilot's activity, effort during flight.

In different flight's phases different aircraft's characteristic are required. So to properly rate control system's influence aircraft's qualities, it shouldn't be taken that same criterions for very different flight's states. Following foregoing argumentation sets of exercises for various flight phases was prepared. So for final approach, it is a flight with simulated ILS signal tracking. But just for holding it is tracing marker determining horizontal coordinated turns.

Schematics below show sample results reached during tests (fig. 2). Pilot's goal was to perform series of turns with roll angle  $30^\circ$ , additionally pitch angle might be kept zero. Roll and pitch angles during such sample tests were demanded as pictograms on a virtual artificial horizon, which also visualized aircraft's space orientation (fig. 3).

There are presented results of series of four tests with various control laws. Pictures presents following a time history of roll angle and pitch angle and pilot's (in degrees of stick's deflection) activity in pitch and roll channel. Studying following figures, it can be seen there are significant differences in accuracy of realizing demanded task. For the first case airplane's behavior was very chaotic. Moreover pilot controlled plane aggressively, he performed great number of stick's movements and they were of high amplitude. It must be mentioned such movements were performed both in roll and pitch channel. Analyzing results for the fourth of used control laws, it can be noticed that aircraft behaved calmly, softly following desired track. Also pilot's activity was more regular (especially in pitch channel). In roll channel significant pilot's movement appeared only when new roll angle was demanded.

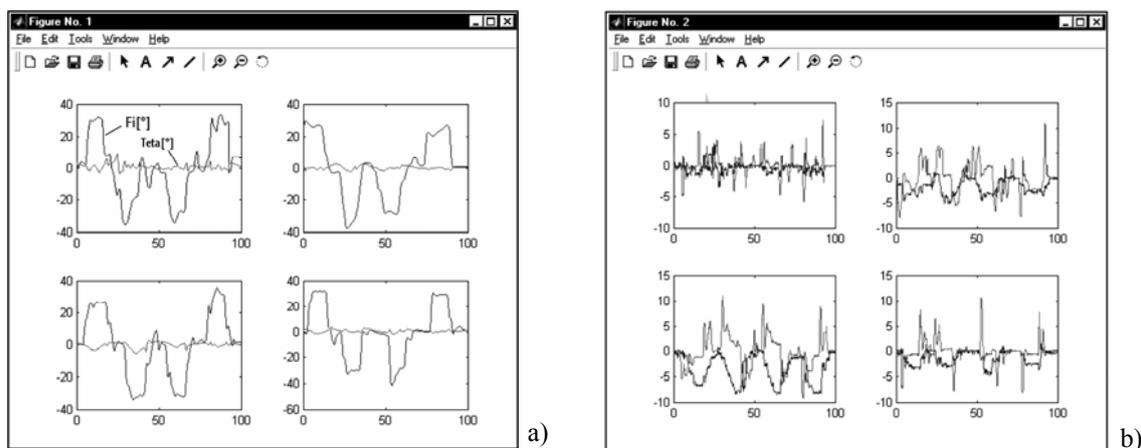


Figure 2. Differences in accuracy of realizing the test maneuver and pilot's afford for various control algorithms - a) time history of roll angle and pitch angle, b) time history of a stick movements in roll and pitch channels.

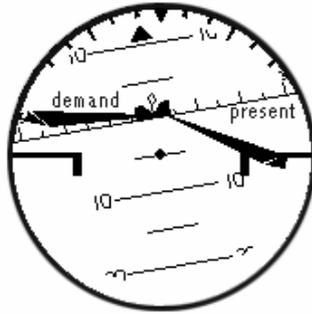


Figure 3. The schematic of the artificial horizon with pictograms illustrating present and demanded plane's space orientation.

## 7. CONCLUSION

Always during work with complex system consisting of autonomous devices cooperating each with other, there is a need to have possibility to test each component and completely integrated system, before it starts work in normal operational conditions. In the case of control system working according to experimental control algorithms, it is necessary to test all of them before they are the first time used in flight.

The laboratory stand, in presented form, will be used both during future researches of unconventional control law for small aircraft and during students works.

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