FLYING TESTS OF CONTROL SYSTEM IMPROVING AIRCRAFT'S HANDLING QUALITIES

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Abstract: *The paper presents results of flight tests of aircraft control system SPS-1. The described control system has been created as a system improving aircraft's handling qualities. During tests several control algorithms were tested. Pilots rated aircraft's handling qualities and were ordered to point control system they liked the most. Additionally original methodology allowing to rate and compare aircraft's handling qualities was tested. It used pilot's workload factor and control's precision to rate aircraft's handling qualities.*

Key words: *handling qualities, control system, aviation.*

1. INTRODUCTION

The development of aviation technology, we can observe, brings growth of aviation transport based on small aircraft. According to foregoing fact a conception of aviation traffic changes. The most characteristic feature of this process is that in selected part of space, on-ground air traffic controllers are not responsible for full organization of aircraft's traffic inside airport's zones and on routes of flight. Full responsibility for safety in airspace is moved to pilots. They are obliged to take decision about a route of flight its speed and height. Pilots are led by both general aviation traffic regulations and information sent from on-ground flight coordination centers. Described kind of aircraft's traffic organization is called "Free Flight" and is more similar to organization of car traffic on highways than to standard airtraffic we know.

Flying by small aircraft is not very difficult, but both the new idea of airtraffic's organization and raising number of not very experienced pilots forces activity going toward simplification of flying by small airplane.

One of elements realizing foregoing tasks is the problem of control systems intended to be installed on the general aviation plane's board to improve airplane's flying characteristics to allow safety fly pilots having no much aviation training [1, 2, 3].

2. THE GENERAL CONCEPTION OF CONTROL SYSTEM

The main assumption in the project of the described control system for small general aviation aircraft modifying its handling qualities is that the system is 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 (fig. 1).

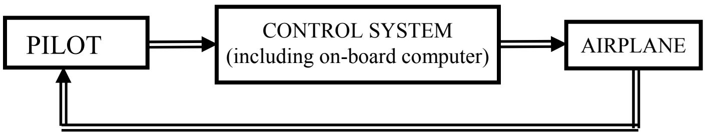

Fig. 1. *The schematic of manual-computer-aided control system.*

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

Proposed conception of control system allows:

- to automatically stabilize flight's parameters 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 SPS-1 were presented in works [2, 3]. Foregoing system have been projected and prepared in Avionics and Control Department of Rzeszow Technical University.

3. EXPERIMENTAL CONTROL LAWS

Experimental control laws were implemented into fly-by-wire control system SPS-1 and tested in flights. Foregoing algorithms worked at three modes of work (modes of control).

1. Mode one; Deflections of control surfaces were proportional to the position of the control device. This mode of work was also called “the direct proportional control”.
2. Mode two (Fig. 2). Deflections of control surfaces were calculated by special forming functions.

3. Mode three (Fig. 3.). Specially prepared regulators of selected flight parameters were used during control of airplane's space orientation.

It is worth noticing there is no direct feedback between state of the plane and the control system in two first cases. Both the plane's dynamics and pilot's impressions close the control loop. Only mode three has direct feedback from plane's state to the control system

As a control device to control flight of the experimental airplane the mini sidestick was used. Its longitudinal and lateral handle's displacements affected adequate aircraft's motion mode. The horizontal roll of the handle replaced the classical control realized by the ruder. More detailed information about experimental control algorithms are included in publications [4, 5, 6].

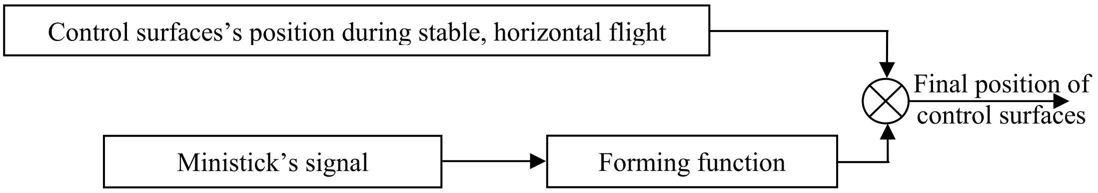

Fig. 2. *The schematic of control law using forming functions.*

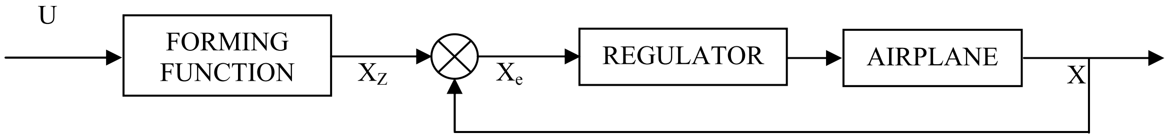

Fig. 3. *The schematic of control laws using regulators of selected flight parameters. U – ministick's position, X – stabilized value of selected flight parameter,* X_z *– demand value of stabilized flight parameter,* X_e *– stabilization error.*

4. THE METHODOLOGY OF GRADING AIRCRAFT'S HANDLING QUALITIES

To measure pilot's effort a parameter *J* (1) was created [6, 7]. Its value depends on both the number and the amplitude of control devices and can approximately define either pilot's effort or pilot's load level.

$$J = \frac{n\sum_{i=1}^{n} M_i}{t_c}; \qquad t\in(0, t_c) \qquad (1)$$

where:

n – number of movements,

M_i – amplitude of i-th movement,

T_c – observation time.

In the case of stabilization maneuvers the most important problem is to precisely keep the demanded flight parameter. Precision of the control process can be well enough described by parameter called “stabilization error” defined by either formula (1) or (2).

$$E_1 = \sqrt{\frac{\int_0^{t_i} (p - p_d)^2 dt}{t_i}} \tag{2}$$

$$E_2 = \frac{\int_0^{t_i} |p - p_d| dt}{t_i} \tag{3}$$

where:

p	– real value of the stabilized flight parameter,
p_d	– demanded value of the stabilized flight parameter,
t_i	– integration time (observation time),
E	– stabilization error (value of parameter describing control precision).

5. SAMPLE RESULTS OF FLIGHT TETST

Projected algorithms modifying aircraft handling qualities were tested in flight [2, 4]. As an experimental plane PZL-110 equipped with SPS-1 control system was selected. During flights the pilot was doing a number of established maneuvers. They were programmed in the way to check plane’s handling qualities during typical operational conditions.

For the longitudinal mode of plane’s movement the maneuver of catching and stabilizing the flight altitude was selected and the course stabilization maneuver to analyze the flight characteristics of lateral one. During the test flight, the pilot, controlled the airplane via following control laws:

1. The direct proportional control when elevator’s deflection was proportional to sideistick’s displacement. - Because of safety reasons, to prevent the airplane against to too dynamical maneuvers, the maximal elevator’s deflection was restricted to ±7.5 [deg], from the position needed to keep the straight, horizontal flight (value chosen experimentally).
2. The control law with the forming function. - In this case the position of the elevator δE was calculated according to the formula (4) on the basis of sidestick’s position X_s. The range of elevator’s deflections was restricted like for the proportional control law.

$$\delta E = \operatorname{sgn}(Xs) \cdot 7.5\left(\frac{Xs}{100}\right)^2 \qquad (4)$$

3. That control law was based on the PID regulator of pitch angle. The forming filter preparing demand value of pitch angle kept by the regulator working as follow (5).

$$\Theta_d = k\int X_s dt \Big|_{\Theta \min}^{\Theta \max} \qquad (5)$$

where Θ_d – demanded value of pitch angle,

k – integration coefficient,

X_s – stick's displacement,

Θ_{min}, Θ_{max} – minimal and maximal permitted pitch angles truncating values demanded signal.

Such form of the control algorithm caused, the pitch rate was proportional to sidestick's position.

Flying tests gave possibility acquiring data used to compare and to rate the work of the SPS-1 with implemented experimental control algorithms. Post flight annualizes enabled both reconstruction of pilot's activity during test maneuvers and plane's flight parameters. On these basics the ranking of control algorithms was prepared (see chapter 4).

Figure 6 and table 1 give the example illustrating reached results. Figures presents flight altitude, during process its stabilization via different control laws. Table 1 include values of two parameters calculated on the basics of acquired data used to grade and compare the work of algorithms (see chapter 4).

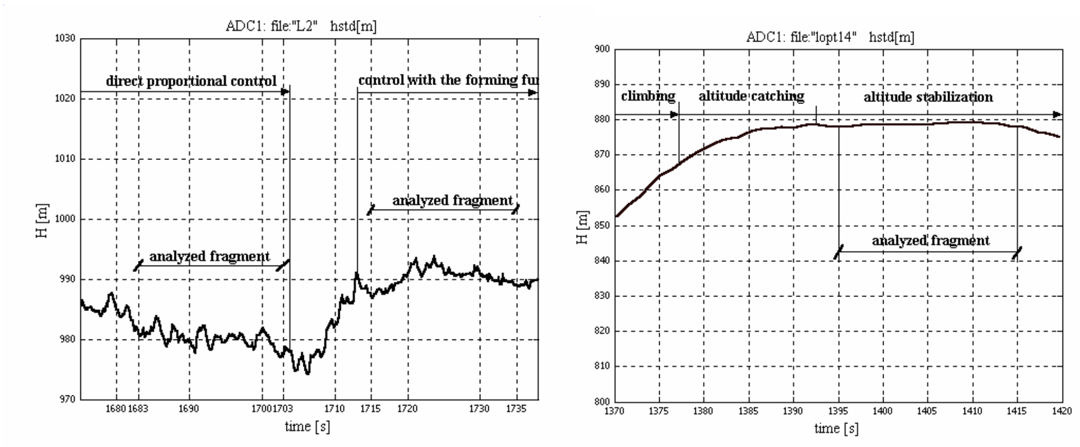

Fig. 6. *The selected fragment of flights when the pilot kept the altitude using tested control laws.*

Table 1. Differences of pilot's effort and coefficients defining control precision for tested control algorithms.

Parameter's symbol	Parameter [unit]	Direct proportional control	Control with the forming function	Control with the controller of pitch angle
E_2	Stabilisation error [m/s]	1.4	1.6	1.6
J	Pilot's effort [%/s]	52	27	0.3

6. CONCLUSION

Flying tests showed the properly projected algorithms could modify aircraft's handling qualities. The plane became easier to fly with. They caused that aircraft's behavior was less nervous, characterized by less variation of space orientations angles.

Algorithms augmenting aircraft's handling qualities which tests are presented in this paper can be split into two groups. The first of them gives maybe little worse results, didn't used any regulators of flight parameters. They also didn't need any devices measuring aircraft's flight parameters. The second group gave better effects but necessity measuring the several flight parameters led to more complicated structure of the control system. Additionally necessary both attitude and heading reference system (AHRS) and aerodynamic data computer (ADC) increased the system's price.

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