

# Modelling of the automatic stabilization system of the aircraft course by a fuzzy logic method

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**Abstract.** The problem of the present paper concerns the development of a fuzzy model of the system of an aircraft course stabilization. In this work modelling of the aircraft course stabilization system with the application of fuzzy logic is specified. Thus the authors have used the data taken for an ordinary passenger plane. As a result of the study the stabilization system models were realised in the environment of Matlab package Simulink on the basis of the PID-regulator and fuzzy logic. The authors of the paper have shown that the use of the method of artificial intelligence allows reducing the time of regulation to 1, which is 50 times faster than the time when standard receptions of the management theory are used. This fact demonstrates a positive influence of the use of fuzzy regulation.

## 1. Introduction

A continuous development of the aircraft industry have complicated the range, time and conditions of the flight. An increase in the range of the flight parametric variations, maximum flight altitude and speed have resulted in the new requirements to the modern aircraft equipment. Besides, unattainability of the required flight characteristics at the expense of existing design of the aircrafts, a raise in the standards of the aircraft control have led to the rise of conditions, under which modern and advanced piloted aircrafts are impossible without modern and ideal systems of automatic and semi-automatic control.

Now the development on improvement of the aircraft autopilot is actively conducted. In works [1-3] the main problems mentioned by developers are an automatic control of the azimuth angle, aircraft pitch angle, automatic piloting and development of the devices for aircraft stabilization.

Designers of the automatic control system of the azimuth angle and a restriction of the normal aircraft overload in [6] searched the solution of a problem of ensuring the necessary accuracy of normal overload restriction when the aircraft turns at a specified azimuth angle. They have found a solution having introduced an automatic machine of normal overload restriction by means of the algebraic selector of the minimum signal into the system of azimuth angle automatic control.

The authors of the design consider the device of automatic piloting equipped with the bearing screw, which is proposed as a way of facilitation of the pilot's control of the aircraft equipped with the bearing screw. The bearing screw contains, at least, one pushing propeller. Such way of facilitation allows minimizing the aircraft aerodynamic drag. This device contains the means of starting of the automated piloting mode allowing one to hold an attack angle constant. This means is connected to the processing block, which in its turn controls a collective blade pitch automatically when the automated piloting mode with holding of the attack angle is switched on. In Russia the similar main designs



belong to the military aviation. The application of artificial intelligence methods for passenger airplanes, in particular a fuzzy controller, has not been revealed yet. Therefore, the task assigned within this paper is actual.

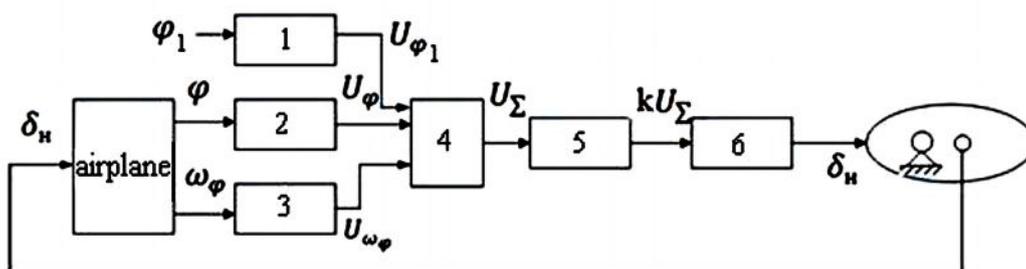
The system under development has to provide an automatic stabilization of the aircraft course necessary for flight realisation according to the azimuth reference. A fuzzy logic application in the modelled system is substantiated by the following advantages: the lack of necessity in the precise mathematical formulation of the controlled object, an opportunity of relatively easy stabilizer resetting and an opportunity of increasing the input variables number.

## 2. Development of the automatic stabilization system of the aircraft course by a fuzzy logic method

Flight control of the aircraft consists in retaining of the predetermined motion path of its centre of mass, orientation and stabilization relatively the centre of mass. The solution of these tasks is provided with automatic or semi-automatic control systems, in which the aircraft is rendered as a control object.

The key parameter, defining the aircraft motion direction, is the course – an angle calculated clockwise between the direction of the meridian and a projection of the longitudinal aircraft axis onto a horizon plane. Depending on the type of the meridian (geographical, magnetic, compass) used as a reference line, there are true, magnetic and compass courses [9]. The aircraft automatic control systems include autopilots, gyroscopes, remote control and inertial systems and others.

The basis of the autopilots scheme when operating in the stabilization mode represents a principle of angle control, angular velocity control and angular acceleration control. System “aircraft-autopilot” is a closed loop system of automatic control and management consisting of three automatic control systems with inner cross connections (a channel of the elevators control, a channel of the ailerons control, a channel of the rudder control). All three systems are usually implemented according to identical schemes. The scheme of the rudder control channel is given in figure 1, where  $\delta_H$  – a deviation angle of the rudder;  $\varphi_1$  – a preset value of the azimuth angle;  $\varphi$  – an azimuth angle; 1 – a setting mechanism of the azimuth angle; 2, 3 – measuring devices (sensors  $\varphi$  and  $\omega_\varphi$ );  $U_\varphi$ ,  $U_{\varphi_1}$ ,  $U_{\omega_\varphi}$  – stresses proportional to values; 4 – a summator;  $U_\Sigma$  – total stress; 5 – an amplifier;  $k$  – an amplifier gain; 6 – a steering engine.



**Figure 1.** A block diagram of the automatic stability control of an aircraft course.

A channel consists of measuring devices 2 and 3, summator 4, amplifying 5 and actuating 6 devices. Measuring devices 2 and 3 of the AP-type autopilot (a banking angle sensor) measure the values of angle deviations and angular speed (azimuth angle  $\varphi$ , azimuth angular speed  $\omega_\varphi$ ) and convert these deviations to stress values  $U_\varphi$  and  $U_{\omega_\varphi}$ . After algebraic summation in summator 4, sum of stresses  $U_\Sigma$  is amplified by amplifier 5 and is fed to the autopilot steering engine, which in

its turn deflects the rudder, as a result of which the emerged azimuth deviation angle is eliminated. For setting of a certain value of azimuth angle  $\varphi$  a setting mechanism of the azimuth angle is provided in the autopilot scheme.

For smoother stabilization of the aircraft it is necessary to consider not only angle  $\varphi$  itself, but also the rate of its variation  $\frac{d\Delta\varphi}{dt}$ . It means that sharper aircraft deviations will correspond to sharper rudders deviations. In this case it is important to take into consideration angular accelerations  $\frac{d^2\Delta\varphi}{dt^2}$  as well. In this case the autopilot's equation for one channel of the course has the following view:

$$\delta_H = k_H \Delta\varphi + k'_H \frac{d\varphi}{dt} + k''_H \frac{d^2\varphi}{dt^2},$$

where  $k_H, k'_H, k''_H$  – transfer ratios of the autopilot by the angle, angular speed and angular acceleration of the course channel, respectively.

In this case the proportional feedback is unnecessary as the rudder deviation will cause the immediate negative acceleration of the aircraft counteracting the disturbing aircraft deviation. When considering a total time signal, the autopilot stabilizes the aircraft along a trajectory, i.e. returns it to its former trajectory of flight. In this case the autopilot's equation for one channel (of the course) is written as follows:

$$\delta_H = k_H \int_0^t \Delta\varphi dt + k''_H \Delta\varphi + k'_H \frac{d\varphi}{dt},$$

Such control is called astatic.

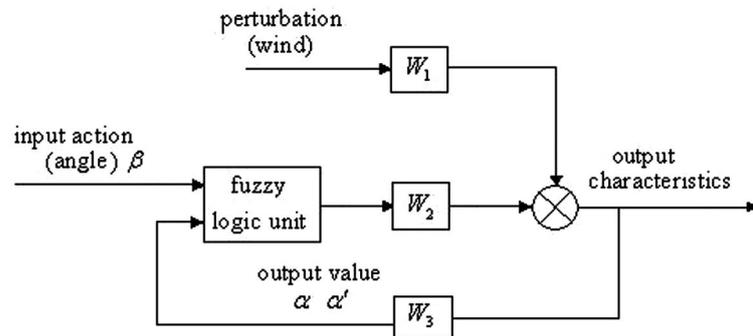
Nowadays flight gyroscopes, remote indicating magnetic compasses, compass systems are applied as sensitive elements reacting to angular aircraft deviations relatively the center of gravity.

For realization of the autopilot with application of fuzzy logic it is necessary to develop a scheme for aircraft behaviour modelling. An aircraft transfer function, which should be fed with the signal from the fuzzy logic block and the output of which should contain a variable equal to the aircraft rudder angle of rotation, is used as initial data. But any system is affected by external disturbances, for example wind, therefore the output characteristic will consist of both a component having passed through the aircraft transfer function and a component of the external disturbance passing through its transfer function. For provision of management, it is necessary to read off the output characteristic, an aircraft angle of rotation, as well as to measure the rate of the rotation angle change. These characteristics should be transmitted to the fuzzy logic block. As a result we obtain the following block diagram presented in figure 2.

Fuzzy system modelling happens in a fuzzy logic package of Fuzzy Logic Toolbox allowing one to design fuzzy expert and/or controlling systems.

For creation of the stabilization system let us formulate necessary fuzzy rules to control the course rudder using Mamdani inference algorithm.

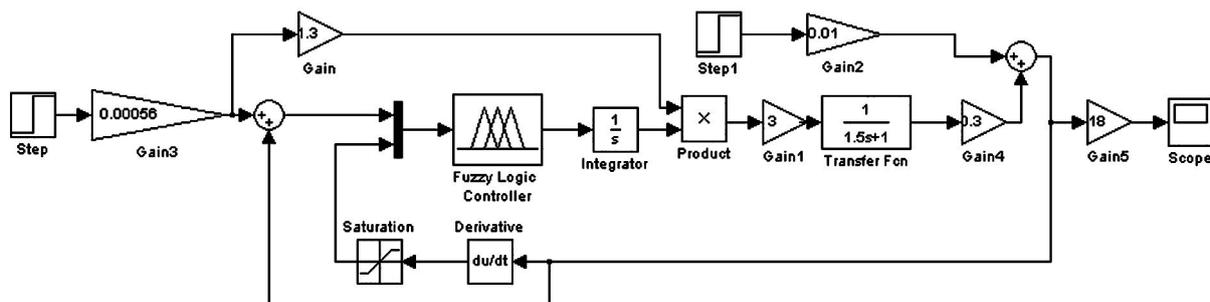
The input variables are the deviation angle of the control rudder and the rate of the rudder deviation angle change.



**Figure 2.** The block diagram of the modelled system.

### 3. Research of an imitating model of the automatic stabilization system of the aircraft course

For creation of the modelled system it is necessary to assemble an imitating model, being guided by the structural flowchart shown in figure 4. An inspection of the operability of the fuzzy controlling device is carried out in the Simulink environment. The scheme used for operability inspection is presented in figure 3.



**Figure 3.** A scheme of the system created in the Simulink environment.

The scheme of the automatic stabilization system of the aircraft course consists of the following blocks [11]:

- Step – a step generator;
- Sum – a block of sum calculation, the sum of the current signal values is calculated;
- Gain – an amplifier, which multiplies an input signal by a constant coefficient;
- Mux – a multiplexer, which unites input signals into a vector;
- Fuzzy Logic Controller – a fuzzy controller;
- Derivative – a block of the derivative calculation;
- Integrator – an integrating block, which integrates the input signal;
- Saturation – a restriction block, which restricts the signal swing/value;
- Product – a multiplication block, which calculates the product of the current signal values;
- Transfer Fcn – a block of the transfer characteristic that sets a transfer function in the form of the polynomial relation;
- Scope – a simulated oscillograph that displays the diagrams of the output signals in the model.

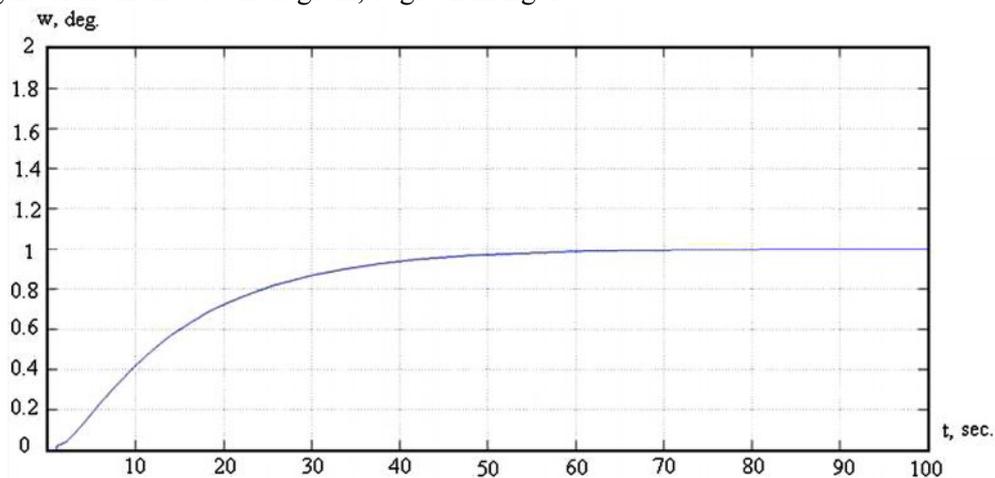
The transfer function of the control object used when modeling the system operation, namely a fuselage, has a view of a lag element of the first order:

$$W(s) = \frac{1}{1.5s + 1}$$

The necessary coefficients used for realisation of the working capacity are:

- a transfer constant of the angle setting mechanism equal to  $1/18 = 0.05556$  V/grad;
- a coefficient of conversion from the voltage signal into degrees equal to  $18$  grad / V;
- a transfer constant of the rudder mechanism equal to  $3$  grad / V;
- a transfer constant of a sensitive element being  $0.3$  V / grad;
- a transfer constant of the perturbation action equal to  $0.001$  grad/N.
- a signal amplification coefficient equal to  $1.3$ .

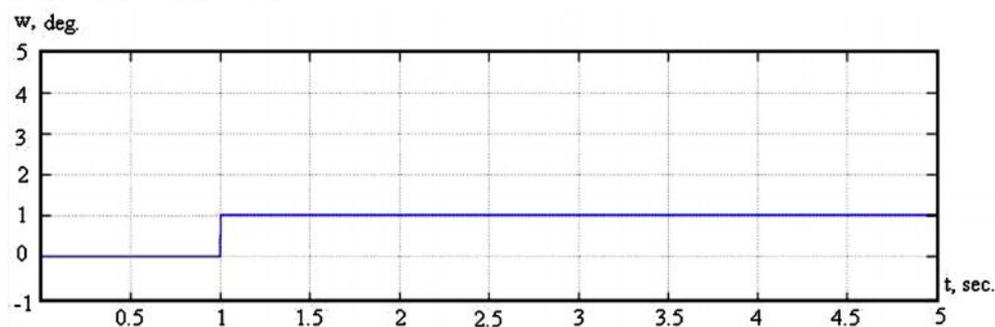
A system response to a single step excitation and the wind perturbation action, when excluding the fuzzy regulator from the block diagram, is given in figure 4.



**Figure 4.** A diagram of the real value of the azimuth angle degree.

As one can see from the diagram, the process is established at the value of  $55$  s, which is not a suitable value by response speed.

In figure 5 the curve of the transition process in the automatic control system, which includes the adaptive fuzzy correcting device, is presented. The input is fed with a unit stepwise impulse as well, and the perturbation action occurs.



**Figure 5.** A diagram of the adjustment of the setting value of the azimuth angle degree (in case the perturbation action deviates towards a greater side).

Thus, the results of modelling have showed that the fuzzy regulator provides high response speed of the system and rather a small error in the established mode. Also it should be noted that for the considered system of the automatic stabilization by the aircraft course of the plane having lags, nonlinearity and feedback, the use of the fuzzy regulator is reasonable since the synthesis of the linear digital regulator is quite a complex and labour-consuming task.

The system considered in the paper demands further development and enhancement, namely an increase of the membership functions and corresponding fuzzy rules, so that there is an opportunity to conduct the experiment at the laboratory aircraft stand.

#### 4. Conclusion

The presented work includes modelling of the automatic stabilization system of the passenger plane course with application of fuzzy logic. The advantage of the similar system is that fuzzy logic does not completely replace traditional techniques of control, and on the contrary it is used in combination with traditional techniques and allows one to simplify the creation and to extend the opportunities of traditional methods. The positive moments consist in the following:

- the experience of operators and developers in adjustment of control and management is formalized and united;
- a simple control method for complicated processes is proposed;
- the experience of controlling the processes of this type is considered, regarding all kinds of exceptions and system peculiarities;
- all kinds of initial data are considered and various initial data are combined.

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