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THE USE OF FUZZY EXPERT SYSTEM FOR AN AUTOMATIC CONTROL OF THE PROPULSION SYSTEM IN THE AIRCRAFT ZLIN 143LSi

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Abstract

The article discusses the manner of controlling the propulsion system in the aircraft Zlin 143LSi, which is equipped with a piston engine driving a variable-pitch propeller. All the operating procedures are carried out manually by the pilot in accordance with the flight manual. The authors attempted at developing the project of a controller based on fuzzy logic, whose main goal was automating the control system of the propulsion unit, thus lowering the level of difficulty of pilotage, and increasing the economics of the operation. The project was made in an interactive environment FuzzyLogic Toolbox of the MATLAB programme. In the analysis, three input parameters were taken into account, exerting an impact on changing the rotational speed of the propeller: the charging pressure of the propulsion unit expressed in inches of mercury, the speed of the aircraft (TAS) in knots and the angle of attack, at which the flight is made, expressed in degrees. On the basis of the above-mentioned input signals, the rotation speed of the propeller was determined, by changing the blade pitch and the recommended angle of attack for the parameters in order to make an optimal use of the data of the flight conditions. The article presents the project of the controller and its optimization. The authors simulated the controller operation in the package MATLAB "Simulink". The article ends with data analysis and final conclusions.

Keywords: *fuzzy logic, fuzzy expert system, propulsion system, aircraft Zlin 143LSi*

1. Introduction

Fuzzy logic generalizes the classical bivalent zero-one logic. Its real values are included in the range between 0 and 1. It is useful in engineering applications, where classical logic is unable to effectively cope with a number of ambiguities and contradictions, and fuzzy logic significantly increases the computational range of a given controller. It is used, among others, in the construction of expert systems [2, 3, 6, 7]. Using the MATLAB programme and its additional software FuzzyLogic Toolbox, an expert system was created computing the rotation speed of the propeller and the recommended angle of attack on the aircraft Zlin 143 LSi, depending on several input signals. These signals are engine pressure charging, the air speed of the aircraft and the angle of attack with which the flight is executed.

2. Subject of research

The aircraft Zlin 143Lsi (Fig. 1), a Czech development, is a low-wing monoplane, made of metal. It is equipped with an 8.875 litre six-cylinder engine, connected to the three-bladed propeller. It has a fixed tricycle undercarriage. In the cabin, there is room for four people: one pilot + three passengers. Steering the propulsion unit is made by levers centrally fitted in the cockpit. They are connected mechanically to the elements controlling the operating parameters. The black lever is responsible for the setting of the charge pressure, the blue lever changes the propeller pitch, causing an increase or a decrease in the propeller rotations, the red lever changes the air-fuel mixture fed into the engine. All the parameters of the drive unit are displayed on the electronic display Garmin G1000. The parameters of proper operation are marked with a green arc on the suitable indicators. In the case of a mechanical control of the revolutions in the aircraft Zlin 143LSi, the control is performed using the blue lever mounted in the cockpit (Fig. 2). Its smooth regulation or turning moves the adjustment spring. In this way, the oil pressure is changed when the oil is fed into the mechanism of the pitch change [1, 4].

Fig. 1. Zlin 143LSi aircraft [9]

Fig. 2. Control levers of the propulsion unit in the aircraft Zlin 143LSi

Nowadays, the aircraft produced from composites (from the smallest ones, such as the Diamond DA20, up to the Boeing 787) are significantly lighter than made of metal, which are characterised by low performance. Although the engine used in Zlin 143LSi develops the power of 240 HP, the aircraft is cumbersome and rather difficult to manoeuvre. Besides, the loss of the power unit causes a rapid loss of altitude and speed.

3. Design of a fuzzy expert system

The model of the fuzzy logic controller was created in the Fuzzy Logic Toolbox software included in the computer programme MATLAB. The authors built a model consisting of three input and two output signals. The controller was named after its function Automatic Control of Power Unit. Consultations with an expert allowed determining input signals, which change the output signal, being the propeller rotational speed. The applied input signals allowed a determination of the additional output signal, whose result will be only be advisory for the pilot – recommended angle of attack.

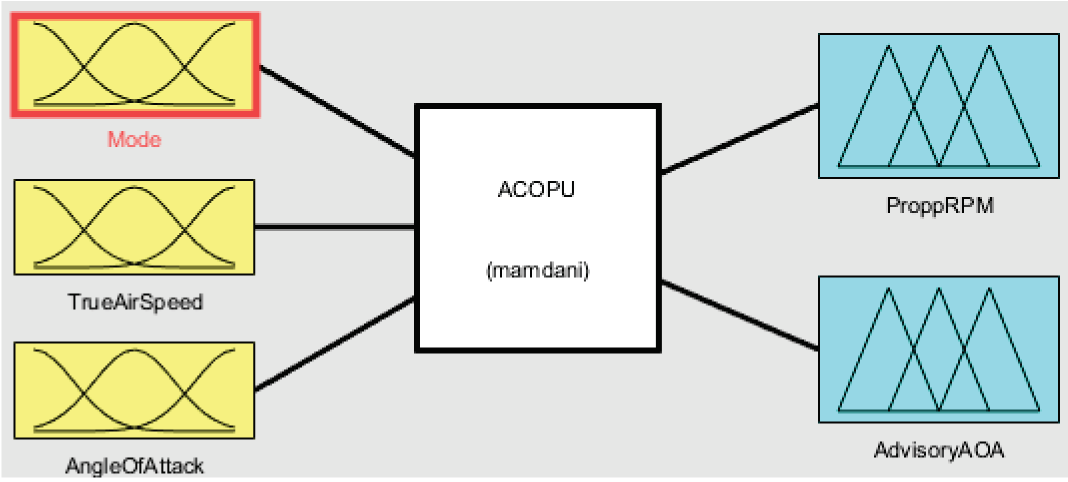


Fig. 3. Fuzzy logic control system

Determination of input and output signals

In designing the system, three input parameters were taken into account, exerting an impact on changing the rotational speed of the propeller: the charging pressure of the propulsion unit expressed in inches of mercury, the speed of the aircraft TAS (*True Air Speed)* in knots and the angle of attack, expressed in degrees [8]. The authors used a trapezoid function in order to introduce the ranges. The entered data are derived from the flight manual of the aircraft Zlin 143LSi.

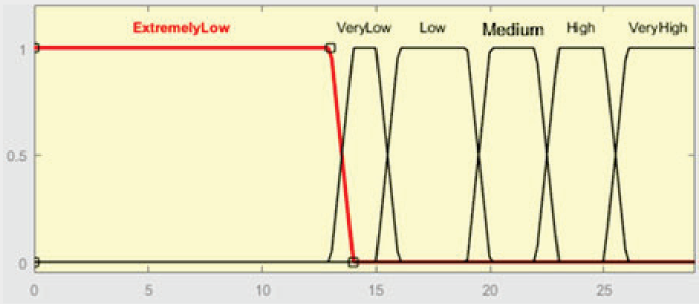
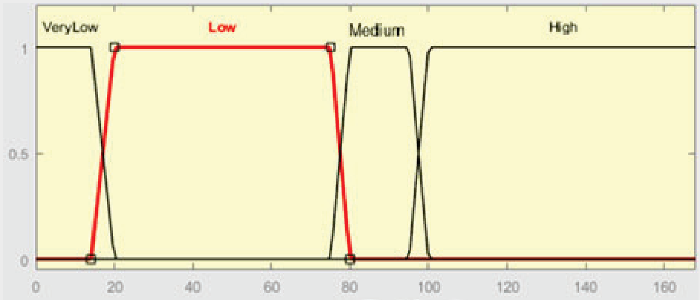
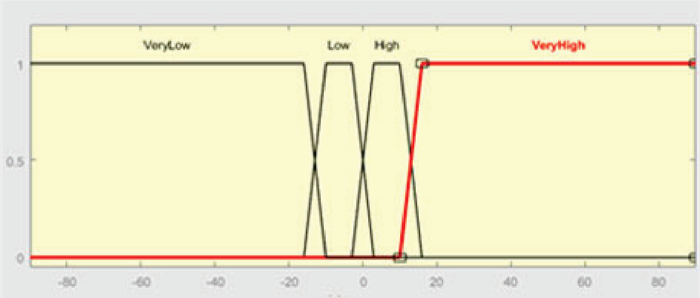
The first input signal (Tab. 1) is the engine pressure charging. On the aircraft Zlin 143Lsi, the correctly working unit has 14-29 inch Hg. Such a value is marked with a green arc on the indicator. The electronic indicator on Garmin G1000 display has a range of 0-40 inch Hg. Above the green arc, the engine or the charging system may malfunction, or become damaged. The value below 13 occurs when the engine operates incorrectly or when it is switched off (the display of charge pressure is equal to zero or 0.1). During the flight, in which there are all phases, from taxiing to take-off, climbing, cruise and then the descent and landing, the pressure changes. The settings of the lever are made by the pilot. The value ranges set by the pilot are known and are included within certain scopes due to the changing conditions of the flight, mainly related to the weight of the aircraft and temperature.

The second input signal (Tab. 1) is the true speed of the aircraft against the air streams floating around the aircraft. Zlin143LSi is the aircraft operating in the speed range of 0-168 knots. The corresponding values and ranges are assigned to the successive phases of the flight. Operating speeds exceed 80 knots. Below this value, the aircraft may stall. The aircraft has the stall speed of 66; however, there are cases where air streams become separated from the wing even at 75 knots. The applied speeds are purposefully inflated so as to avoid such a situation.

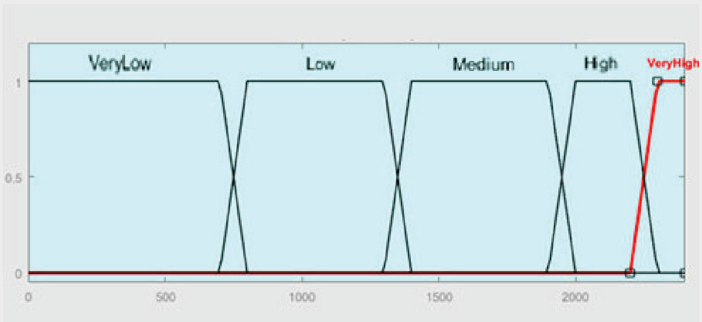
The third used input signal (Tab. 1) is the angle of attack of the aircraft. During normal operating conditions, low angles of attack are used. During the flight, the usual angle of climbing and descending are within ±15 degrees from the horizontal position. Larger angles are used in emergency situations. The aircraft angles of attack are visible on the electronic display Garmin G1000 on the artificial horizon.

The output signal is the speed of the propeller and the recommended angle of attack. With the set values of input signals, the revolutions of the propeller should be within a certain range. Their adjustment is made by changing the propeller pitch – the larger the pitch, the slower the revolutions. The recommended angle of attack is determined to economically use the propulsion unit and the actual flight parameters. In addition, it will allow the protection of the aircraft against hazardous situations such as the speed drop to the stall speed. The membership functions of the output signal are presented in Tab. 2 and 3.

Tab. 1. Membership functions and their ranges for input signals

Input signal	Membership functions
Mode (engine pressure charging) [inch Hg]	*Extremely Low* [0 0 13 14] *Very Low* [13 14 15 16] *Low* [15 16 19 20] *Medium* [19 20 22 23] *High* [22 23 25 26] *Very High* [25 26 29 29] 
True Air Speed [knots]	*Very Low* [0 0 14 20] *Low* [14 20 75 80] *Medium* [75 80 95 100] *High* [95 100 168 168] 
Angle of attack [deg]	*Very Low* [-90 -90 -16 -10] *Low* [-16 -10 -3 3] *High* [-3 3 10 16] *Very High* [10 16 90 90] 

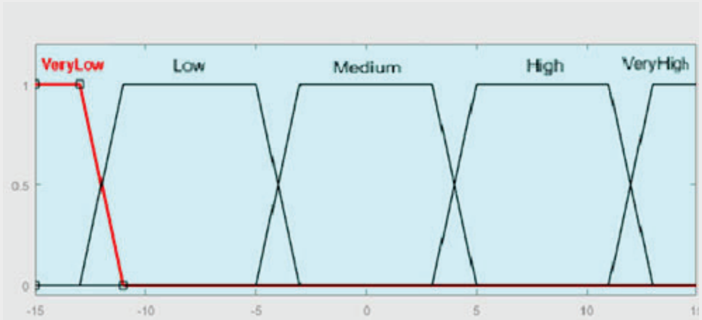
Tab. 2. Membership functions and their ranges for the output signal "Speed of the propeller"

Output signal	Membership functions
Speed of the propeller [r/min]	*Very Low* [0 0 700 800] *Low* [700,800 1300 1400] *Medium* [1300 1400 1900 2000] *High* [1900 2000 2200 2300] *Very High* [2200 2300 2400 2400] 

Building the base of deduction principles

Another step in designing the fuzzy logic control system is establishing a base of principles for deduction. Three input signals: one signal comprising 6 sets and two signals with 4 sets. In a research project being performed, there are 96 deduction principles. It is extremely important to avoid repetition of the rules and use all combinations of input signals [5]. Consultations with an expert allowed the development of input signals, output signals as well as the base of principles. The project of an automatic control system was discussed. Its scope, form of operation, and the benefits of using it on the aircraft were demonstrated. The expert concluded that its use was justified, as its implementation will largely facilitate the pilotage of the Zlin 143Lsi, making the aircraft more economical. Examples of deduction rules are presented in Fig. 4.

Tab. 3. Membership functions and their ranges for the output signal "Recommended angle of attack"

Output signal	Membership functions	
Recommended angle of attack [deg]	*Very Low* [-15 -15 -13 -11] *Low* [-13 -11 -5 -3] *Medium* [-5 -3 3 5] *High* [3 5 11 13] *Very High* [11 13 15 15]	

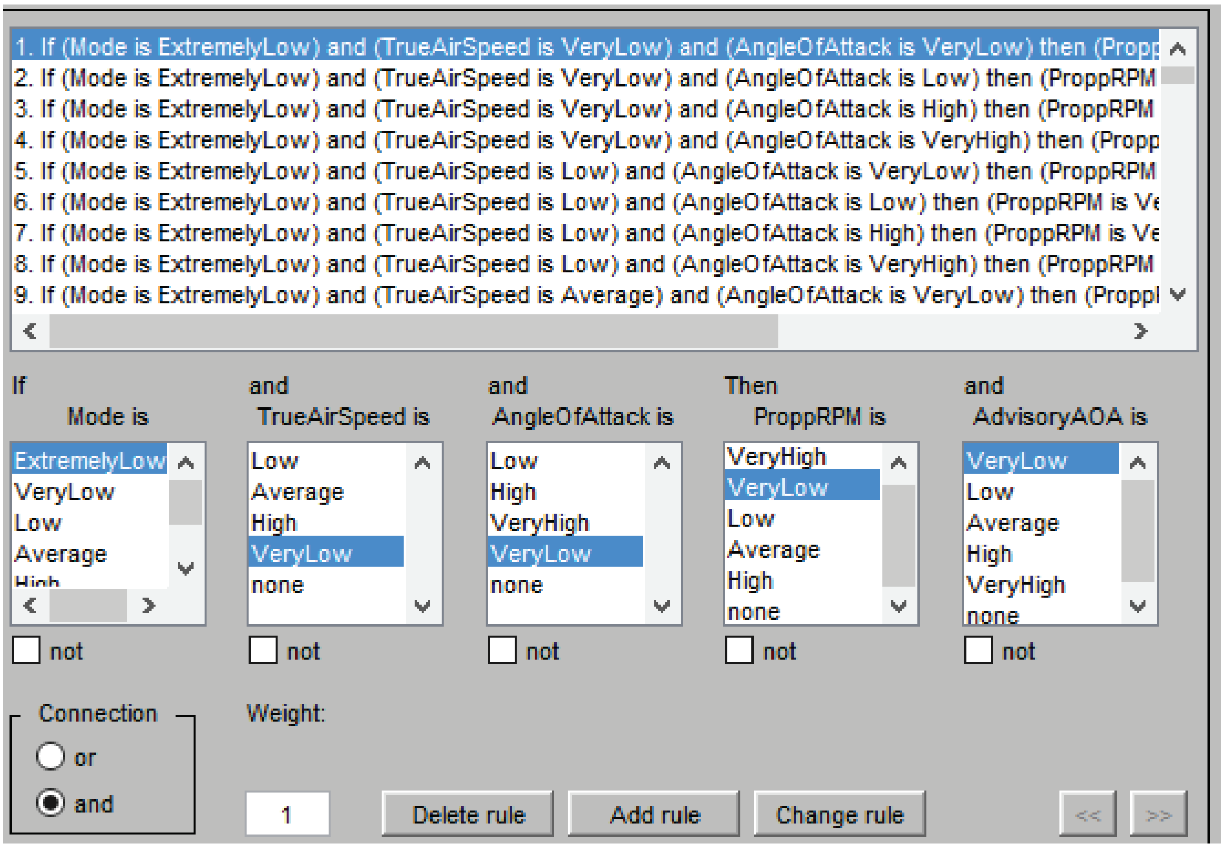


Fig. 4. Deduction rules

Analysis of proper system performance

Once all the necessary system parameters had been specified and the principles of deduction had been determined, it was possible to proceed to the analysis of the controller's operation. Therefore, were selected 20 samples of input signals for the analysis. The test results are presented in Tab. 4.

Tab. 4. Remaining samples after the examination of the controller

No	*Engine pressure charging*	*Speed of aircraft*	*Angle of attack*	*Speed propeller*	*Recommended angle of attack*
1	24	69	77	1,660	-13.5
2	18	129	28	1,060	0
3	18	129	-40	1,660	7.8
4	23	129	-4	2,020	13.5
5	28.3	9.24	0	2,160	-13.2
6	23.9	9.24	0	1,800	-13.2
7	20.4	98.3	74.7	1,940	-2.1
8	22.8	79.8	74.7	1,990	-1.2
9	22.5	105	0	1,800	9.3
10	22.5	105	2	1,800	8.4
11	14.5	84	0	1,060	-8.1
12	27.7	84	0	2,330	8.1
13	12.8	93.2	-9.9	360	-8.1
14	19.4	155	49.5	1,150	0
15	20	117	0.9	1,630	8.1
16	20.5	115	8.1	1,660	8.1
17	17.9	88.2	-40.5	1,660	0
18	7.03	160	-80.1	360	0
19	28.3	14.3	-0.9	2,230	-13.5
20	28.3	31.1	-0.9	2,330	-13.5

Having conducted, the investigation on the designed fuzzy logic system it was found that it does not operate correctly. Some samples, marked red in the table, show incorrect values of the rotational speed. The indicated recommended angle of attack is correct for all samples. The programme has defects, which arose during the design and the building phases. It is necessary to create new principles, focusing primarily on the rotational speed of the propeller. Establishing deduction principles was easier for the recommended angle of attack. Nevertheless, the created rules must be revised and established anew.

Optimization

The designed system has several disadvantages. It is necessary to carry out optimization, which aims at eliminating the observed errors at the research stage. After an examination of the designed fuzzy logic control system of the propulsion unit in Zlin 143LSi aircraft, a defect was found in the form of several poorly created principles in the base. Optimization is intended to eliminate the errors and re-examination of the object on the same values that were given during the first investigation. Improperly created principles resulted in erroneous results in several cases. Again all the 96 principles were re-examined in order to eliminate the errors. A consultation with an expert and the conducted investigation led to the determination of incorrect principles rules and their re-formulation. It pointed to an incorrect formulation of principles in 24 cases. In addition, the input signal relating to the angle of attack was also reduced. The minimum and the maximum angle value may be sporadically used; however, the values, which are below 30 or above 30, are not used during normal flying conditions. The range was reduced from 90 to 30 degrees. In order to check the results of the conducted optimization, the object needs to be re-examined on the same samples, as it was the case during the testing of an unoptimized controller (Tab. 5).

Tab. 5. Findings of examining 20 data samples after system optimization

No	*Engine pressure charging*	*Speed of aircraft*	*Angle of attack*	*Speed propeller*	*Recommended angle of attack*
1	24	69	30	1,660	-13.5
2	18	129	28	1,660	0
3	18	129	-30	1,660	7.8
4	23	129	-4	2,090	13.5
5	28.3	9.24	0	2,090	-13.2
6	23.9	9.24	0	2,110	-13.2
7	20.4	98.3	30	1,940	-2.1
8	22.8	79.8	30	2,020	-1.2
9	22.5	105	0	2,110	9.3
10	22.5	105	2	2,110	8.4
11	14.5	84	0	1,060	-8.1
12	27.7	84	0	2,330	8.1
13	12.8	93.2	-9.9	360	-8.1
14	19.4	155	30	1,750	0
15	20	117	0.9	2,090	8.1
16	20.5	115	8.1	2,090	8.1
17	17.9	88.2	-30	1,660	0
18	7.03	160	-30	360	0
19	28.3	14.3	-0.9	2,230	-13.5
20	28.3	31.1	-0.9	2,330	-13.5

After system, optimization was obtained the control surface, as shown in Fig. 5

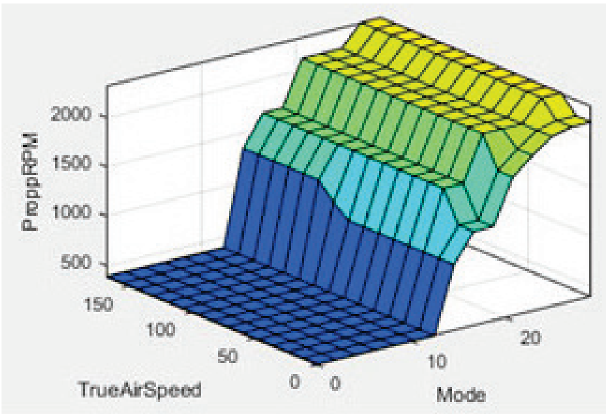


Fig. 5. Control plane showing the dependence of propeller rotational speed and engine pressure charging as well as aircraft speed

4. Conclusions

The software package Fuzzy Logic Toolbox enabled the authors to programme a controller to steer the propulsion unit, consisting of an engine and a propeller. A well-developed system is capable of calculating the correct values. The package can be used to create a variety of controllers; however, it is necessary to possess the know-how. The expertise was the basis for determining input signals, output signals as well as building a base of principles. The re-examination of the controller and another consultation with an expert identified errors, which emerged in the phase of design and consequently led to their elimination through optimization. New tests proved that the controller works properly and may undergo further tests, for example, simulations in the Simulink tool of the MATLAB programme. A further stage of the research on the proposed controller will focus on a more accurate simulation as well as tuning the controller so as to undertake attempts to implement the proposed solution in the Zlin 143LSi aircraft.

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