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THE DESIGN AND SIMULATION OF AN AUTOMATED DE-ICING CONTROL SYSTEM IN THE AIRCRAFT DIAMOND DA42

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Abstract

The article discusses the automatic control system of the Diamond DA42 aircraft anti-icing system. In the analysis of the issue of icing, four parameters were taken into account: air temperature, cloud humidity, temperature of the aircraft and precipitation. On the basis of the initial parameters, the authors determined the icing intensity, which is likely to occur on the aircraft skin. By automating the activities related to the activation of the de-icing system, it is possible to significantly relieve the pilot and increase the safety of air operations, particularly in conditions, which are conducive to the formation of icing. The authors performed a thirty-minute electronic simulation of the flight in real atmospheric conditions. The article discusses the obtained results of the simulation. Designed system uses fuzzy logic. The system inputs and output were determined and fuzzy expert inference system was developed in MATLAB software and Fuzzy Logic Toolbox. The proper system work was verified with use of MATLAB/Simulink software. Use of that kind of systems can significantly relieve the pilot and increase the safety of air operations, particularly in conditions, which are conducive to the formation of icing.

Keywords: *anti-icing installation, icing, Diamond DA42, aircraft, general aviation, MATLAB*

1. Introduction

Simulink is a graphical tool for systems design [8] from different areas of technology, for example mechanical systems or electrical systems in one coherent environment. Almost everything, which can be described in a mathematical-physical manner or can be presented in the form of a flowchart, can be modelled in this environment. Simulink is a graphic programming language for systems, in which we rely on a flowchart referred to as a model. The algorithm is presented in the form of a diagram composed of geometric blocks. The blocks represent functions and their proper juxtaposition as well as combination is successive phases of the performed algorithm. For the purposes of this project, the authors developed the expert system, which calculates the intensity of icing on the aircraft Diamond DA42, taking into account four input signals, namely: air temperature, cloud liquid water content, temperature of the aircraft and precipitation. A simulation of a thirty-minute flight in order to check the operation of the controller in set atmospheric conditions was also conducted.

2. Object of research

The object of research was the de-icing installation mounted on the aircraft Diamond DA42. The principle of operation of this installation relies on the principle of spraying sensitive surfaces with a special agent. This substance known as glycol, when mixed with water, decreases the freezing point of the resulting mixture. The aircraft surface, covered with the solution, becomes resistant to the accumulation of ice, by preventing the freezing of water molecules.

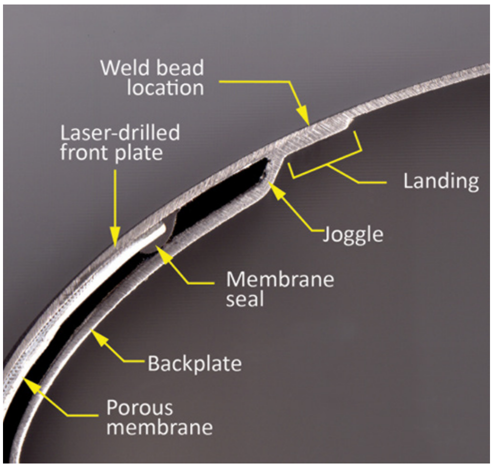

Fig. 1. Cross-section of the wing with a mounted de-icing installation TKS [9]

The installation effectively prevents the accumulation of dangerous ice on the front surfaces of the airframe. The biggest problem is the determination of the conditions conducive to icing and activation of the installation at a proper time by the pilot. When it is done too late, the accumulated ice, which is present on the de-icing plates, covers the slots for glycol. This will result in a total loss of effectiveness of the described installation. According to the manufacturer [1] [2], the system may knock off only rudimentary ice. In case the ice cap is larger than rudimentary, the effectiveness of the installation drops to zero. A solution might be a self-activating system that will switch on automatically at the right time. This would largely relieve the pilot, increasing the safety of the performed air operations. Nowadays mechanical detectors and detecting heads are available which indicate the presence of atmospheric, conducive to icing, factors. However, there is no device, which would calculate such a probability. In response to the current state, the authors developed a controller calculating the intensity of icing based on four input signals.

3. Project of the fuzzy controller

The fuzzy controller was designed in the MATLAB environment and the package Fuzzy Logic Toolbox. On the basis of the four input signals, it is possible to calculate the icing intensity. The control signals in this case are the ambient temperature, cloud humidity, temperature of the aircraft and precipitation. A selection of the described signals was determined on the basis of subject literature [3] [4] [5] [6] and confirmed by an expert.

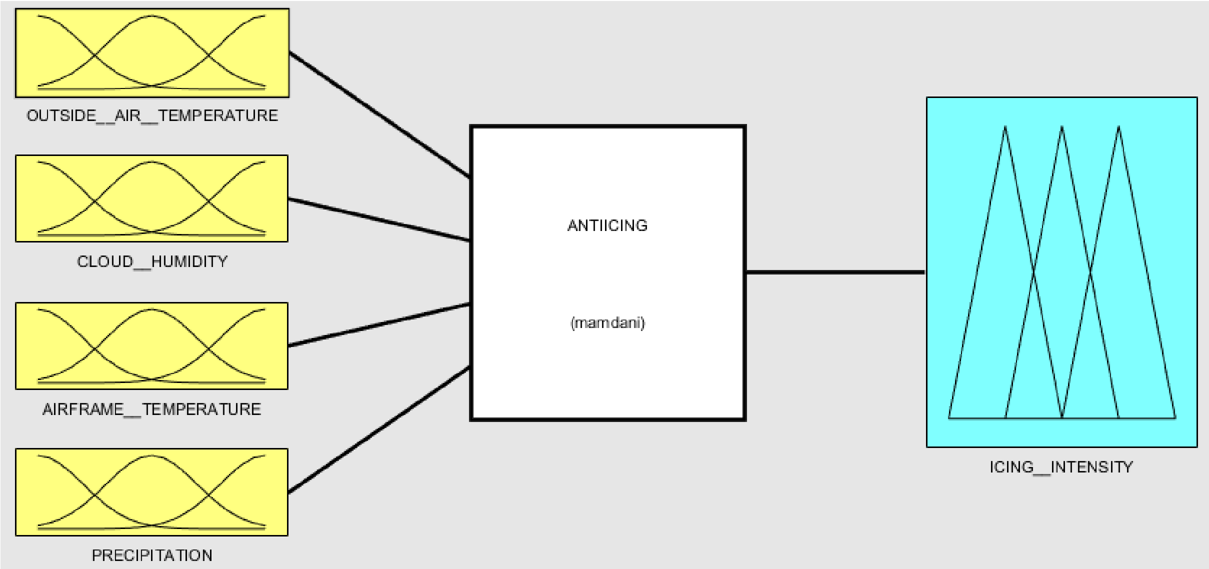

Fig. 2. Design of a fuzzy logic controller in Fuzzy Logic Toolbox package

The foundation of the controller's operation is selection of a suitable base of rules. They consist of deduction principles, on which the operation of the system is based. Its appropriate design determines the effectiveness and efficiency of the generated calculations. The selection of the base of principles relied on the subject literature, i.e. atmospheric and technical factors, in which icing is formed. The work of the controller was initially tested through a verification of 35 samples of test data, which were to reproduce the actual weather conditions conducive to icing.

4. Simulation of the fuzzy logic controller

The simulation of its operation was developed in the Simulink environment, which is an integral part of the computer programme MATLAB. The simulation is to check whether the controller is able to compute the appropriate intensity of icing on the simulated flight route with properly set input signals. The planned route runs from Deblin to Rzeszow. Its duration equals 30 minutes.

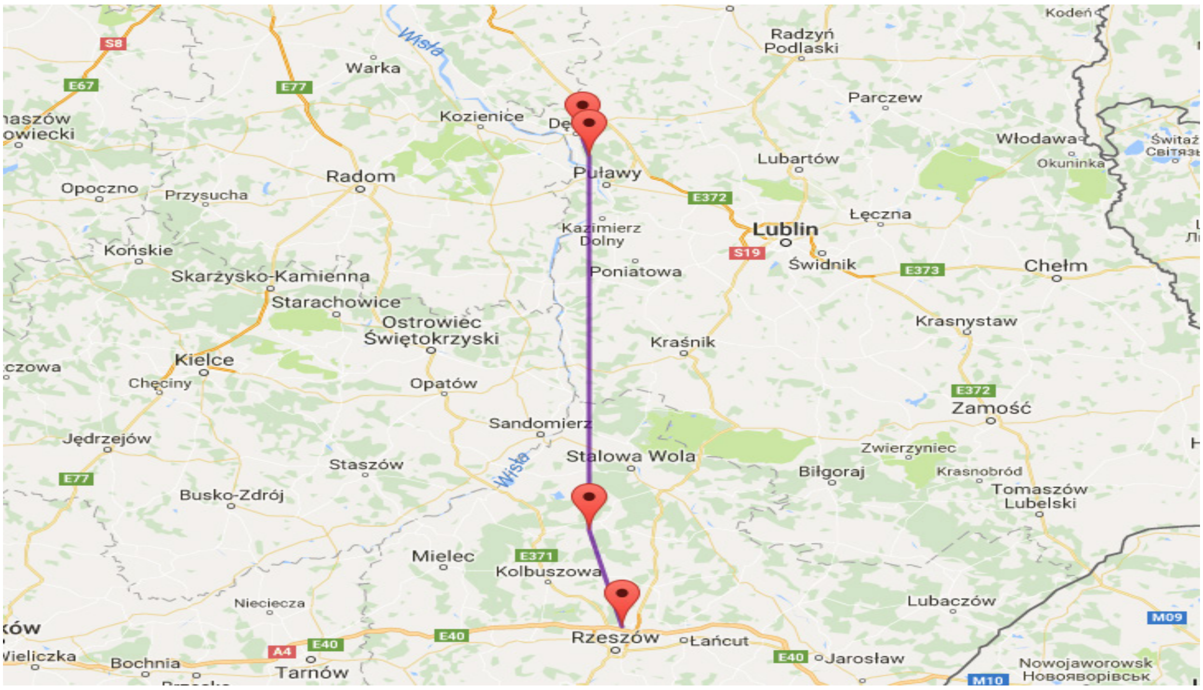

Fig. 4. Simulated route of flight

The simulated flight will be executed at different altitudes to simulate real weather conditions and enforce entering conditions, which are conducive to icing. The flowchart of the controller is shown in Figure 5:

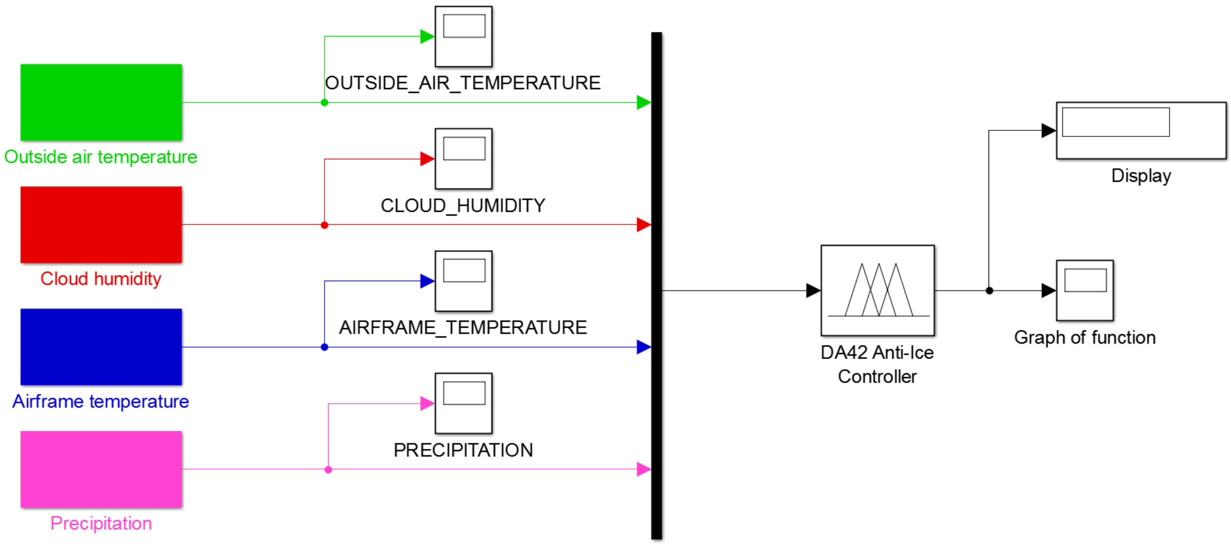

Fig. 5. Flowchart diagram

In order to reflect reliable weather conditions manually designed, graphs of function were designed for each of the input signals. The Simulink package has the option of determining graphs of function. In order to reproduce the conditions, which are most similar to real ones, they were created on the basis of temperature gradients. An appropriate balance of atmosphere was also adopted. In this way, various conditions, which are prevailing in the Earth's atmosphere, were set.

The first of the designed functions is outside air temperature. Initially, the aircraft is taxiing on the taxiways of Deblin aerodrome. The air temperature equals or^{c}. After the take-off, the temperature falls to −9°C and remains at this level for up to 7 minutes of the flight. Next, the Diamond DA42 descends to 5,000 feet above the ground. On the graph of the function, the ambient temperature clearly rises up to approximately 7°C. In the 17th minute of the simulation, the aircraft climbs to FL120. There is a sudden drop in the ambient temperature to −30°C. Such a temperature is maintained until 26th minute into the flight, when the aircraft is making an approach to landing at Rzeszow airport; the air temperature increases.

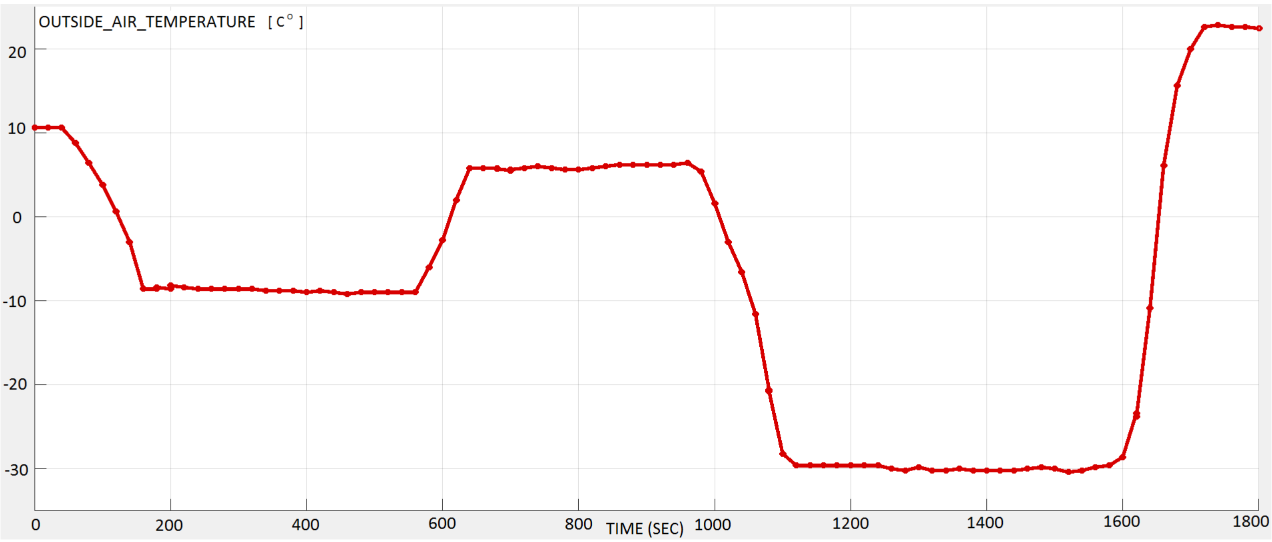

Fig. 6. Graph of functions for the air temperature input signal

The second of the designed functions is cloud humidity. It reflects the simulated change in the cloud humidity for 30 minutes. From the start of the simulation until 6th minute, the water is not visible in the atmosphere. After 6th minute into the flight, the cloud humidity is increasing rapidly until it finally reaches more than 4 g/m^3 and remains at that level until the 12th minute into the flight. This means that the aircraft has flown into a very dense cloud. In 12th minute, it is possible to observe a sharp decline in cloud humidity. At this point, the aircraft comes out of the cloud and is flying away from clouds until 16th minute. After 16th minute of the flight, the cloud humidity is on the rise again, which is due to an increase in the flight altitude.

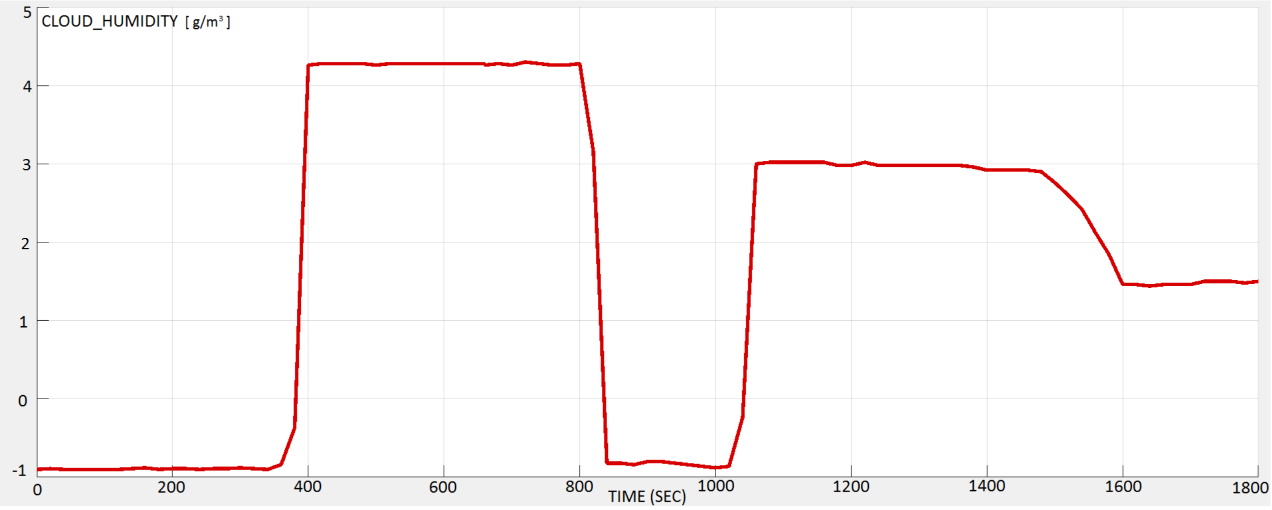

Fig. 7. Graph of functions for the cloud humidity input signal

Another signal is the temperature of the aircraft. In its graph, the function resembles that of the air temperature, however, in its shape, it looks slightly slimmer. The reason is gaining ambient temperature more slowly by the aircraft. At the time when the ambient air temperature drops, the construction takes on its temperature; however, it occurs with some delay, which can be clearly seen in the graph of the function. The alignment of the air temperature with the temperature of the aircraft construction requires a certain amount of time. The temperature of the aircraft may also depend on other factors, which are independent of weather conditions, for example, cold fuel pumped into the tanks cools the entire construction. Another factor is the colour of the aircraft. Most of the aircraft are white, since this colour absorbs the sunrays to a lesser degree, thus preventing the airframe from excessive heating.

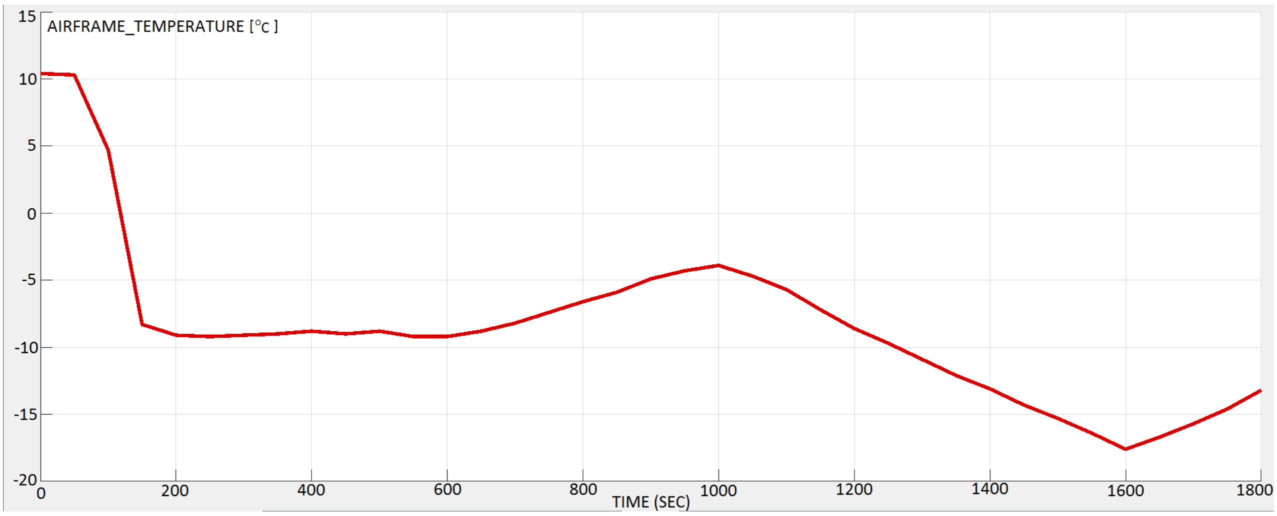

Fig. 8. Graph of functions for the temperature of the aircraft input signal

The function of precipitation was designed as the fourth one. It demonstrates the precipitation activity, which occurred during the flight. From minute 6 to minute 9 of the simulation, one may notice a shower, which is typical of a cold front.

The designed graphs were created so as to test the controller in different atmospheric conditions. The conditions encountered on the route of the flight are conducive to not only the emergence of icing, but also its prevention. The assumption was to obtain the effectiveness of the work of the controller in any conditions, which will be examined in the graph of the function obtained at the output.

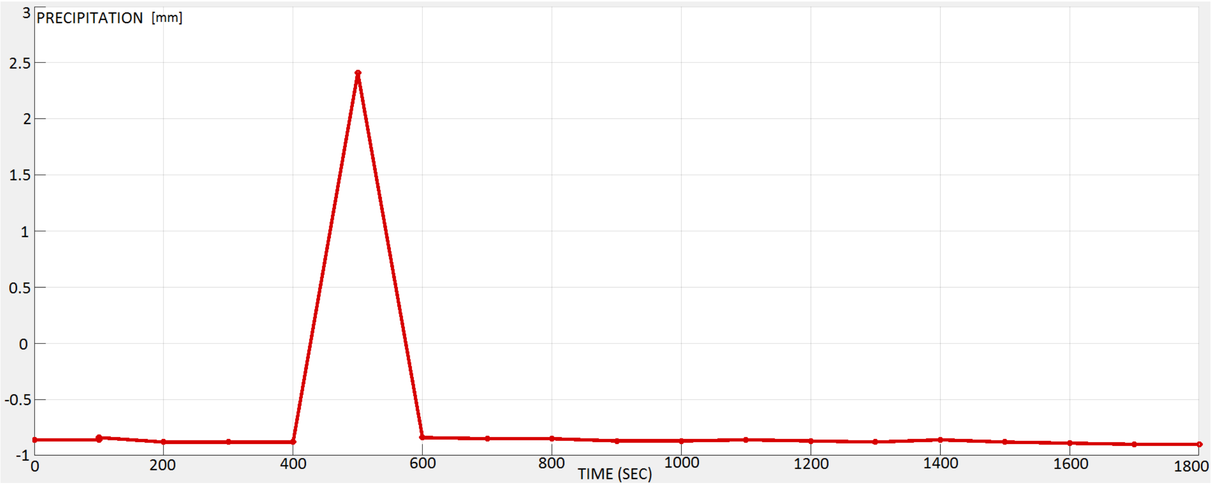

Fig. 9. The graph of function for the precipitation input signal

The generated graph of function is based on the previously introduced parameters. It shows the controller's response to set input signals. The output signal of the first 7 minutes does not show any signs of icing. Despite the freezing temperatures of the airframe and negative ambient air temperature of -9ºC, the icing does not occur. The function is maintained at the value level of 13%. This value is included in the "NO ICING" function. The result is consistent with the assumptions. For the presence of icing conditions on the airframe, apart from a proper air temperature and the aircraft temperature, the presence of water in the visible state is also essential. As it is visible on the graph of cloud humidity, water in the visible state does not occur in the first 7 minutes of the flight. In the next 3 minutes of the flight, one may notice a sharp increase in the icing. The reason is an increase in the cloud humidity and the presence of heavy rain. In accordance with the deduction rules, there were conditions, which were strongly conducive to icing, which is confirmed by the generated graph, which maintained the value of 88% of the intensity of icing, at this stage. This value was classified as heavy icing. Judging by the deduction rules, when the temperature range is between 0ºC and −20ºC, the airframe temperature is negative, there is a strong precipitation, and the cloud humidity is between 1.5 g/m^3 and 5 g/m^3, the icing will be heavy. Between 10th and 17th minute into the flight, there is a decrease in the intensity of icing up to 13%, which denotes the absence of icing. When analysing the graphs of function of the input signals, one may easily notice that up to 13th minute, the cloud humidity remains at the level of 4 g/m^3, however, the intensity of the icing does not rise. This is due to the fact that the precipitation had stopped completely. Moreover, the aircraft reduced the flight ceiling, reaching a positive ambient temperature. Despite the negative temperature of the airframe, icing did not occur owing to the prevailing conditions, which were unfavourable to its formation. Between 17th and 18th minute of the flight, again there occurs a growth in the intensity of icing, and then its decline. During this time, the plane begins to climb to FL120. The cloud humidity also begins to rise. At this point, the aircraft crosses the isotherm of 0ºC and is flying through a cloud. This results in immediate increase in the intensity of icing despite a positive temperature of the airframe and a lack of precipitation. From 17th to 24th minutes of the flight, the aircraft maintains FL120. On the basis of the generated function graph, it was possible to read the icing intensity of 36%, which means moderate intensity and the work of the installation in the NORM mode. Despite the cloud humidity at a level of 3 g/ m^3 and a negative airframe temperature, the icing intensity remains at a moderate level. The cause of such a function graph is the air temperature of -30ºC. At such a temperature, icing is quite unlikely since the water in the atmosphere occurs in a solid state, forming ice crystals. In such a low temperature, the ice granules do not form a deposit on the structure of the aircraft, being merely bounced back, thus creating hardly any risk. Between 24th and 25th minute of the flight, the graph of function again skyrockets to the intensity of icing at the level of 88%. This is caused by the aircraft descent, prior to landing. The aircraft leaves FL120 and begins the descent, which results in a temperature increase. During this time, the aircraft crosses a range of temperatures, from −20°C to 0ºC, flying through the temperature envelope which is most favourable to ice depositing. Despite the drop-in weight of the liquid content of the clouds, the decisive factor proves to be temperature. The programme computed a very strong intensity of icing, which is consistent with the *status quo* and the assumptions. After crossing the isotherm of 0 °C, the intensity drops to 13% and remains at that level until taxiing the plane at the apron in Rzeszow airport.

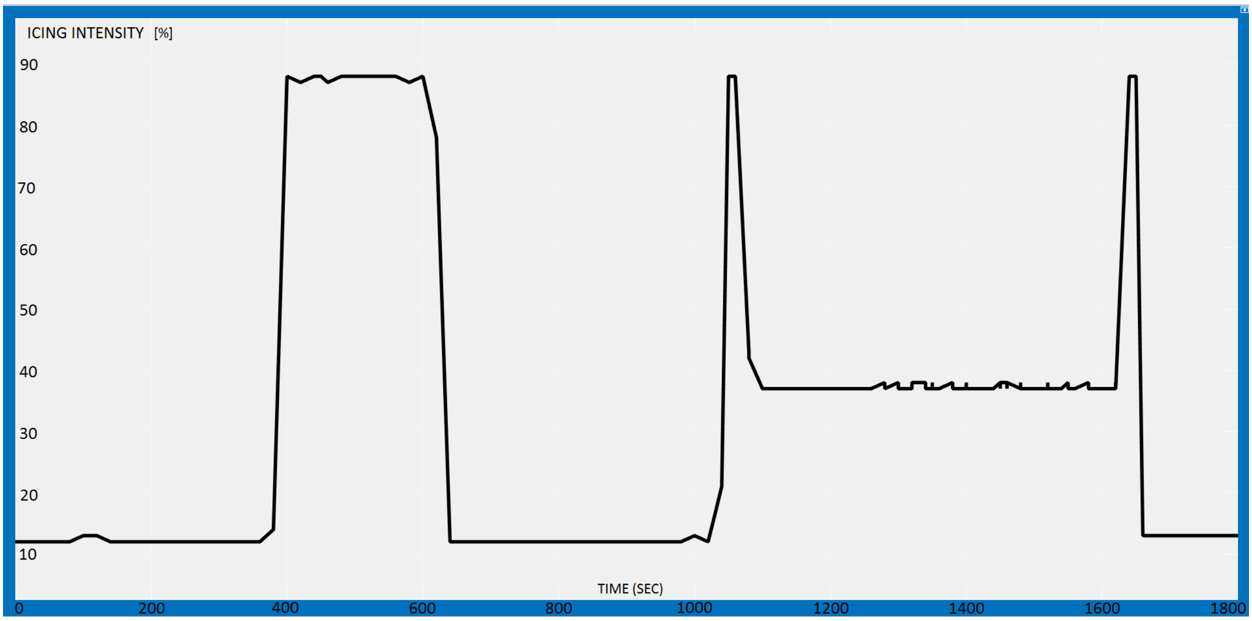

Fig. 10. The graph of function for the intensity of icing output signal

5. Conclusions

The programme MATLAB and the Simulink software package allowed simulating the actual flight of the aircraft. Proper atmospheric conditions were set in order to verify the efficiency and the correct operation of the fuzzy controller. The output response was correct. Introduced rules of deduction, based on the available literature and expertise, confirmed the correctness of the result. Despite the diversity of the set signals, the fuzzy controller indicated a response, which was consistent with the true one, throughout the duration of the entire simulation. In case of the implementation of the system into the aircraft, the pilot would not have to unnecessarily focus on the automatic de-icing installation on board the operated aircraft. This, in turn, would result in an enhanced security of the executed operations.

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