Determining the Level of Flight Crew Readiness Based on Fuzzy Logic Approaches

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Abstract

The application of aviation as the main mobile firepower in achieving the objectives of military operations today is obvious and necessary. In solving a number of important tasks for aviation in practice, it is necessary to be able to assess the effectiveness of the aviation group. The effectiveness of aviation application depends on a number of factors, most of which are unmanageable. Therefore, the authors chose the level of flight crew readiness in the study as the main factor that can be influenced by taking into account the indicators of crew readiness and their subsequent appointment on missions with different levels of complexity.

In the article, the authors analyzed the indicators that affect the readiness of the flight crew, which make up the specifics of a particular task. Qualitative indicators of the level of readiness and their compliance with the complexity of the relevant missions are determined. Quantitative values of qualitative indicators of the level of crew readiness were also obtained.

The article proposes a method of determining the readiness level of the flight crew, taking into account: the total flight hours, the flight hours for 12 months, the flight hours of personal improvement, breaks in flights and the age of a pilot.

The methodology considered in the article could increase the efficiency of fighter aviation application by reducing the time for the commander in the decision-making process and the exclusion of the subjective approach in the decision-making process.

An algorithm for methodology for determining the level of crew readiness has been developed. The algorithm of this technique is implemented by the software package MATLAB: Simulink and Fuzzy Logic Designer.

Keywords

readiness level, fighter aviation, flight crew, mission, fuzzy logic, aviation application

1. Introduction

Taking into account the influence of the flight crew readiness degree on the success of the flight task (combat missions) is carried out by entering the appropriate coefficient C_{prep}. In the works [1, 2, 3, 4] for the flight crew of tactical aviation the level of preparation considers only the level of class qualification. And according to [5] the level of class qualification takes into account only the total flight hours and exercises that have been completed in the relevant training course. That is, in works [1, 2, 3, 4], it is said that the pilot of the first class, or the pilot-sniper when performing combat missions uses all combat capabilities inherent in the combat aircraft without exception.

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Therefore, the coefficient of flight crew readiness of these class qualification levels is proposed to be equal to one ($C_{prep} = 1$) [6]. For a flight crew with a level of qualification lower than the first class, the values of this coefficient are assigned depending on the passage of the relevant training course and the total flight hours acquired by them ($C_{prep} < 1$). This does not take into account weighty indicators that effect on the readiness level of crews to perform specific combat missions [7]. The readiness level does not have clear boundaries. In conditions when there are no clear boundaries of readiness level, the raised problem can be solved quite successfully with the use of fuzzy logic which is successfully implemented in MATLAB software which authors use for building a fuzzy logic system. Fuzzy set theory is one of the mathematical theories designed to formalize indefinite information for solving analytical problems. Therefore, the purpose of this work is to determine the scientific and methodological apparatus using fuzzy logic approaches to determine the readiness level of the flight crew with taking into account weighty indicators.

2. Algorithm of determining the readiness level of the flight crew

At the stage of decision-making for flights and combat missions, the aviation commander assesses the situation, hears and analyzes the proposals of his deputies, heads of services, commanders of aviation units, commanders of support units, etc. [8,16]. Commander relies on his own experience and intuition. The decision is made in conditions of some uncertainty.
Obviously, the higher the readiness level of the flight crew to perform the task, the higher probability of its successful completion. In times of shortage, the commander must be able to clearly identify the crew to perform a specific combat mission.

To perform calculations by the fuzzy logic apparatus, it is necessary to create an algorithm of determining the readiness level, which will allow assigning flight crews on different types of missions based on the results of determining their readiness level. This algorithm is shown in Figure 1.

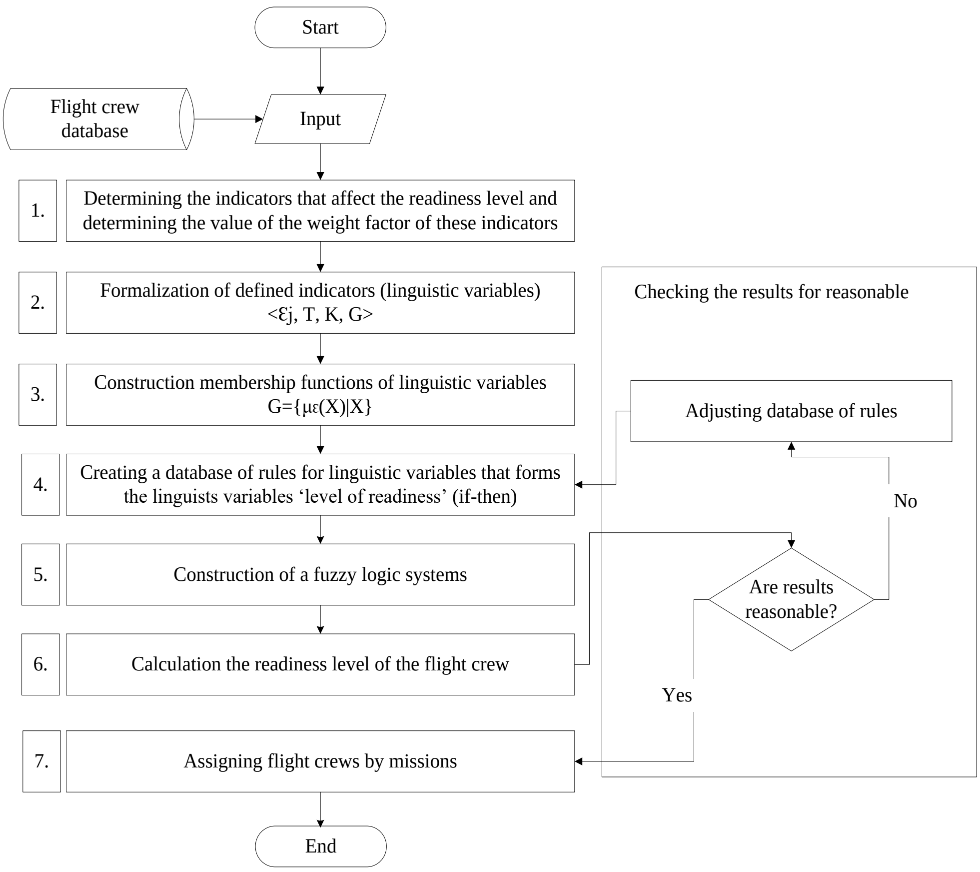

Figure 1: Algorithm of determining the readiness level of the flight crew

To determine the effectiveness of the fighter aviation application it is necessary to investigate all the factors that affect the readiness level of the flight crew and identify the main ones. But these factors have no clear boundaries. In conditions when there are no clear boundaries, the problem can be solved quite successfully using fuzzy logic. The fuzzy logic theory is one of the most suitable mathematical theories designed to formalize indefinite information for solving these kinds of issues.

2.1. Description of the algorithm steps

Step 1. Selection of indicators to determine the readiness and formation of input data. That is, to decide the flight crew appointment to perform the particular mission will be used to quantify the readiness of the crew. The group of experts determines by voting the five indicators that have the greatest impact on the level of readiness of the flight crew.

Step 2. Formalization of the assessment of input readiness indicators as a tuple is carried out, $<\mathcal{E}j, T, K, G>$ where Ɛj – name, T – terms, K – boundaries, $G=\{\mu\mathcal{E}(X)|X\}$ – membership functions [7].

Definition of terms for linguistic variables that characterize the level of readiness of the flight crew and the linguistic variable “level of readiness”.

Step 3. Construction of membership functions of linguistic variables. At this step, the limits of the terms selected to determine the level of readiness and for the linguistic variable "level of readiness" are also set. The construction of membership functions is carried out based on regulatory requirements and expert assessments.

Step 4. Determining the relationship between input and output data in the form of linguistic rules "if - then".

Step 5. Building a fuzzy logic system for each subsystem using the graphical toolkit Fuzzy Logic Designer, from the MATLAB software package. In this application there is a choice of either Sugeno or Mamdani system [9,15]. The functions of membership should be determined through statistics and consultation with aviation experts. In this research, the authors use the Mamdani fuzzy inference algorithm. This is the most common inference in fuzzy systems. It uses a minimax composition of fuzzy sets. The centroid of area method of Defuzzification was used.

Step 6. The initial readiness level of the flight crew is calculated and its values are checked for reasonable. The operation of each fuzzy logic block is checked so that it gives the expected initial values and, therefore, confirms that the developed method of analysis is acceptable.

After that, need to run several launches with different input values, and compare the results with each other. The aim is to determine whether the results are reasonable for the model to give realistic and consistent results. After confirming this, the result should be checked for acceptable limits set for the type of operation. If necessary, appropriate adjustments are made.

The assessment of the initial level of readiness is being formalized. Also, values are determined, as well as the choice of the required fuzzy inference algorithm.

Step 7. The obtained values of the readiness level are compared with quantitative indicators that correspond to the values of the linguistic variable "level of readiness" and then appoint flight crew on a mission with an applicable level of complexity.

Next, consider an example of calculating the readiness level of flight crews for fighter aviation.

3. Calculation of the readiness level of flight crews for fighter aviation

Since quantitative values of variables are required to formalize t-he decision-making algorithm, use fuzzy logic methods to assess the qualitative indicator of the level of readiness [10], namely, place on the scale of the value of the linguistic variable “the level of readiness”:

1. dangerously low (corresponds to value 1 – the pilot needs additional training)
2. low (corresponds to the value 2 – the pilot is able to perform disruption (violation) of enemy air freight cargo missions)
3. medium (corresponds to a value 3 – the pilot is able to perform missions of defeating enemy airborne troops in the air)
4. sufficient (corresponds to the value 4 – the pilot is able to perform the missions of destroying the air threat means of the enemy over own territory)
5. high (corresponds to value 5 – the pilot is able to perform the missions of destroying the air threat means of the enemy over hostile territory)

Since the readiness level is considered as the probability of implementation of the mission, the quantitative assessment of the readiness level should be in the range from 0 to 1.

Divide the selected interval into 10 segments. The degree of belonging of a value is defined as the ratio of the number of responses in which the value of a linguistic variable occurs in a certain interval, to the maximum value of this number at all intervals. Authors conducted a survey of 40 aviation experts on prominent questionnaires.

The results of calculations performed on the survey analysis are given in Table 1.

Table 1
The results of the experts' survey

value	Interval, unit									
	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1
1	24	12	4	0	0	0	0	0	0	0
2	0	6	21	11	2	0	0	0	0	0
3	0	0	0	3	7	21	9	0	0	0
4	0	0	0	0	0	0	11	18	11	0
5	0	0	0	0	0	0	0	3	13	24
k_j	24	18	25	14	9	21	20	21	24	24

To process the data, we use a hint matrix, which is a string with elements defined by the equation

$$k_j = \sum_{i=1}^{5} b_{ij}\,, \qquad j = \overline{1.10} \qquad (1)$$

The hint matrix in this case has the form:

$$M = \|24\ 18\ 25\ 14\ 9\ 21\ 20\ 21\ 24\ 24\|$$

Choose the maximum element from the hint matrix:

$$k_{max} = \max_j k_j = \\ = max\{24; 18; 25; 14; 9; 21; 20; 21; 24; 24\} = 25$$

and convert the elements of table 1 according to the equation

$$c_{ij} = \frac{b_{ji} k_{max}}{k_j}, i = \overline{1.5}, j = \overline{1.10} \qquad (2)$$

The results of the calculations are put in Table 2, on the basis of which the membership functions are built.

Table 2
Processing of survey results

value	Interval, unit									
	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1
1	25.0	16.7	4.0	0	0	0	0	0	0	0
2	0	8.3	21.0	19.6	5.6	0	0	0	0	0
3	0	0	0	5.4	19.4	25.0	11.3	0	0	0
4	0	0	0	0	0	0	13.8	21.4	11.5	0
5	0	0	0	0	0	0	0	3.6	13.5	25.0

To do this, find the lines of the maximum elements by the equation

$$c_{1max} = \\ = \max_j c_{ij}, i = 1.2, \dots, m, j = 1.2, \dots, n \qquad (3)$$

and receive next result:

$$c_{1max} = 25.0; c_{2max} = 21.0; c_{3max} = 25.0; \\ c_{4max} = 21.4; c_{5max} = 25.0$$

The value of the membership function is found by the equation

$$\mu = \frac{c_{ij}}{c_{imax}} \qquad (4)$$

The results of the calculations are given in Table 3.

Table 3
The value of the membership function

μ_i	Interval, unit									
	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1
μ_1	1	0.67	0.16	0	0	0	0	0	0	0
μ_2	0	0.40	1	0.94	0.26	0	0	0	0	0
μ_3	0	0	0	0.21	0.78	1	0.45	0	0	0
μ_4	0	0	0	0	0	0	0.64	1	0.53	0
μ_5	0	0	0	0	0	0	0	0.14	0.54	1

Fuzzy logic theory does not oblige to choose the type of membership function absolutely clearly or precisely [11,14]. It can be clarified in the research process based on the results of solving the problem. The most common are triangular, trapezoidal and bell-shaped membership function, which will be used in the proposed model. Predetermined intervals of fuzzy sets are the basis for constructing the membership function of input linguistic variables.

The membership functions for each value of the linguistic variable “level of readiness” are shown in Figure 2.

Figure 2: The membership functions of the value of the linguistic variable “level of readiness”

From the obtained diagram it is possible to determine quantitative indicators that correspond to the values of the linguistic variable “level of readiness”. Display these values in Table 4.

Table 4
Quantitative and Qualitative indicators of the level of readiness in decision-making tasks

Mission	Qualitative assessment	Quantitative assessment
Not allowed	Dangerously low	0.1
Disruption of enemy air freight cargo missions	Low	0.35
Defeating enemy airborne troops in the air	Medium	0.6
Destroying the air threat means of the enemy over own territory	Sufficient	0.8
Destroying the air threat means of the enemy over hostile territory	High	1

That is, to decide on the appointment of the crew to perform the mission, the commander will use the quantitative assessment of the readiness of the crew from Table 4.

4. Indicators that affect the readiness level of the crew to perform the mission

The directive documents regulating the procedure for training and conducting flight training in the state aviation of Ukraine stipulate that the preparation for flight crew flights is the process of bringing the flight crew into readiness for flight tasks [8]. But the readiness of the flight crew is an integral property and complex psychological formation of the military pilot's personality, which manifests itself as a mental state of his readiness for flight activity and provides optimal mental functioning and reliability of knowledge, skills, and abilities to control technical systems of combat aircraft in various flight conditions [12, 13,17-19]. Taking into account these definitions, the authors analyzed the indicators that may effect on the readiness level of flight crew.

In research authors found that the readiness level of flight crew to perform combat action that constitute the specifics of each type of mission depends on a large number (more than 30) indicators. However, for the study, experts identified 5 main indicators that have a greater impact on the final result. These include the total flight hours, the flight hours for 12 months, the flight hours of personal improvement, breaks in flights and the age of a pilot.

Using the same method used to determine the readiness level of the flight crew, the authors calculated these indicators.

4.1. The total flight hours

The total flight hours is compared to the experience, the larger it is the easier it is for the pilot to perform any task that he has encountered in his flying activities before.

The total flight hours in the study is considered as a pilot's flight hours on all types of aircraft for all years of flight activity, including training in Air Force Academy and flight schools outside the service in the Armed Forces of Ukraine.

The flight hours on simulators and the operating time on the ground during engine' star up and taxiing are not taken into account.

To describe the membership function of the linguistic variable “Total flight hours” the terms were named T = {dangerously low; low; medium; sufficient; high} and their limits in flight hours K = [50, 700] were determined.

The maximum value of each term was taken as 1.

The membership function for the linguistic variable “The total flight hours” built in Microsoft Excel is shown in Figure 3.

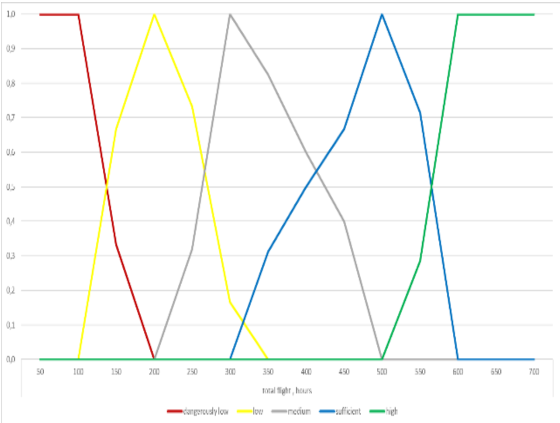

Figure 3: The membership function of the value of the linguistic variable “Total flight hours”

4.2. The flight hours for 12 months

The flight hours for 12 months in the study is considered to be flight hours on all types of aircraft on which the pilot has flown in the last year at the time of data input.

The authors and experts also took into account the organizational and methodological recommendations of the Command of the Air Force on the implementation of annual flight hours per year.

To describe the membership function of the linguistic variable “The flight hours for 12 months” the terms were named T = {dangerously low; low; medium; sufficient; high} and their limits in flight hours K = [10, 140] were determined. The maximum value of each term was taken as 1.

The membership function for the linguistic variable “The flight hours for 12 months” built in Microsoft Excel is shown in Figure 4.

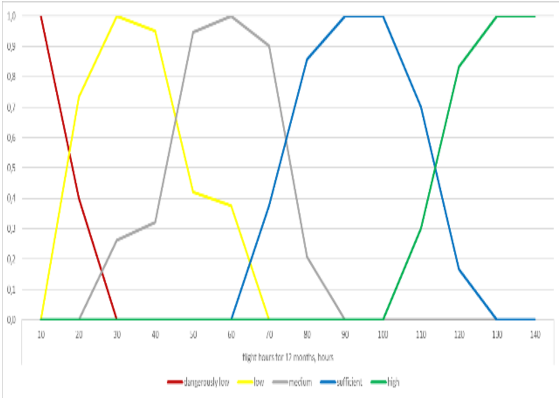

Figure 4: The membership function of the value of the linguistic variable “The flight hours for 12 months”

4.3. The flight hours of personal improvement

The flight hours of personal improvement is the percentage of flights performed by the pilot in the interest of advancing on the appropriate training course. The value of the flight hours of personal improvement is taken into account for the last year at the time of data input in percentage in relation to the flight hours for 12 months only on the main type of aircraft (combat aircraft).

To describe the membership function of the linguistic variable “The flight hours of personal improvement” the terms were named T = {dangerously low; low; medium; sufficient; high} and their limits in percentage K = [10, 100] were determined. The maximum value of each term was taken as 1.

The membership function for the linguistic variable “The flight hours of personal improvement” built in Microsoft Excel is shown in Figure 5.

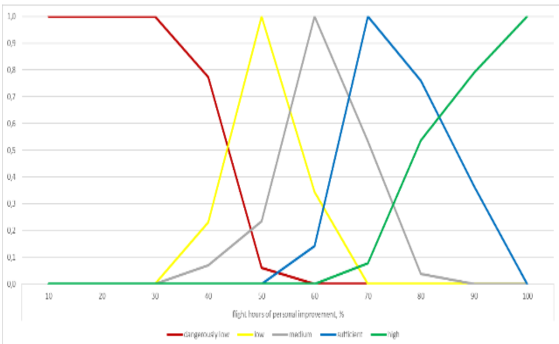

Figure 5: The membership function of the value of the linguistic variable “The flight hours of personal improvement”

4.4. Breaks in flights

In considering the linguistic variable “Breaks in flight”, the author and experts, in addition to the empirical approach, took into account the requirements of the Fighter Training Course and the Rules of State Aviation. These documents set requirements for breaks in flights by type of training and meteorological conditions.

To describe the membership function of the linguistic variable “Breaks in flight” the terms were named T = {dangerously high; high; medium; acceptable; slight} and their limits in days K = [3, 42] were determined. The maximum value of each term was taken as 1.

The membership function for the linguistic variable “Breaks in flight” built in Microsoft Excel is shown in Figure 6.

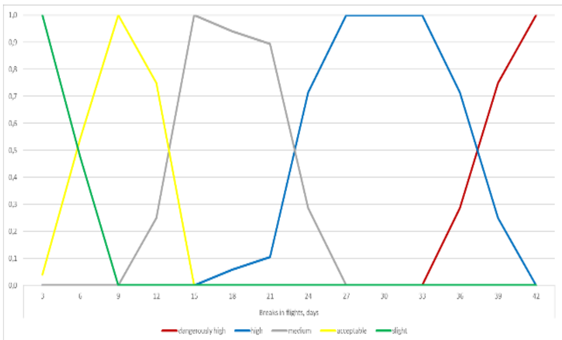

Figure 6: The membership function of the value of the linguistic variable “Breaks in flight”

4.5. Pilot’s age

To perform tasks, the specifics of which are the speed of reaction and the body's ability to resist g-force during combat maneuvering, an important indicator that affects the progress of the task of the flight crew is its age. The value of the linguistic variable “Pilot's age” is understood by authors and experts as the length of the period from birth to the time of data input.

To describe the membership function of the linguistic variable “Pilot's age” the terms were named T = {unsuitable; admissible; suitable; optimal; regular} and their limits in years K = [20, 70] were determined. The maximum value of each term was taken as 1.

The membership function for the linguistic variable “Pilot's age” built in Microsoft Excel is shown in Figure 7.

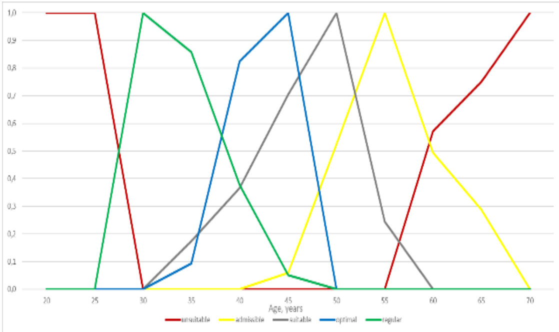

Figure 7: The membership function of the value of the linguistic variable “The flight hours of personal improvement”

5. Simulink model for calculating the level of readiness and appointment flight crews by missions

Based on the analysis of indicators that affect the level of crew readiness, the obtained quantitative indicators of the value of the linguistic variable "level of readiness" and processing of expert data, a hierarchical structure of the flight readiness level tree and their distribution by tasks in Simulink and shown in Figure 8.

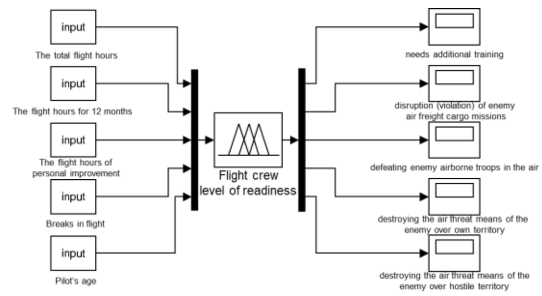

Figure 8: Simulink model of the flight crew level of readiness and appointment flight crews by missions

6. Construction fuzzy rules

Fuzzy control simulation is performed using the Fuzzy Inference System (FIS). For each FIS unit Model of calculation of the level of readiness and distribution of crews by tasks (Figure 8.) it is necessary to define a system of fuzzy rules.

Fuzzy rules “if-then” are the core of a fuzzy logic system because they combine all the other components and determine the output of the system. When assessing the level of readiness, input data are often assigned as indicators and results as readiness. Then fuzzy rules “if – then” are established for the ratio of readiness and set of indicators with a certain level of linguistic tolerance [14]. For example, the following is a fuzzy rule “if – then”, consisting of two inputs and one output:

IF indicator 1 is low, AND indicator 2 is high, THEN readiness is average

The rules are built systematically, looking at all possible combinations of fuzzy sets of each input from the smallest to the largest. The consequences are adjusted so that the smallest sum of fuzzy sets is equal to the minimum, and the largest sum is equal to the maximum value of readiness. Subtotals are interpolated between these two values. The number of rules is the product of the number of fuzzy sets of each input. For example, for FIS “flight crew level of readiness” the number of logic inputs - 5, the number of terms of the output function - 5, the number of rules is $5^5 = 125$.

7. Crew readiness assessment results

The calculation of clear readiness values is carried out in the Simulink environment. The calculation model is presented in Figure 8. The input data are data of the total flight hours, the flight hours for 12 months, the flight hours of personal improvement, breaks in flights and the age of a pilot. At the output we get a numerical value of the readiness level from 0 to 1. An example of the obtained values is shown in Figure 9.

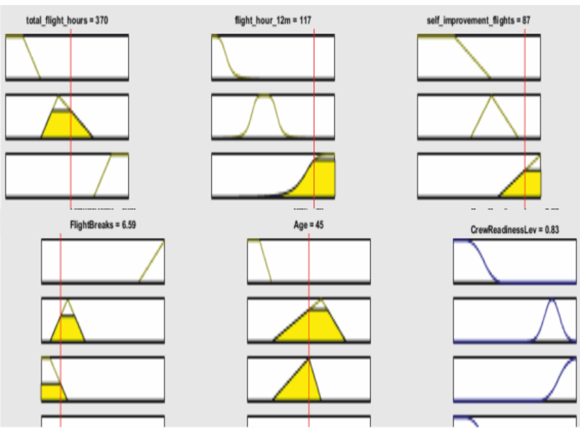

Figure 9: The calculation of clear readiness values in the Simulink environment

After receiving the numerical values of the crew readiness level, the obtained values are compared with the quantitative indicators of the “flight crew level of readiness”. Depending on the complexity of the task, this figure varies. In case of discrepancy between the level of complexity of the task and the level of readiness of the crew, appropriate changes are made to the input data, the crew or task is replaced. If the level of readiness and complexity of the task corresponds, the crew is assigning to a mission.

8. Conclusions

Thus, the authors analyzed the indicators that affect the readiness of the flight crews, which constitute the specifics of each particular task. Qualitative indicators of the level of readiness and their compliance with the complexity of the relevant missions are determined. Quantitative values of qualitative indicators of the readiness level of flight crew were also obtained.

The algorithm of determining the readiness level of the flight crew has been developed. The algorithm is implemented by the software package MATLAB: Simulink and Fuzzy Logic Designer.

The proposed methodology will allow to quantify the readiness level of the flight crew, to take timely measures to organize effective training of crews for possible tasks. By reducing the time in decision-making process in assigning flight crews on missions, taking into account the level of readiness of crews, and exclusion of a subjective approach in solving this task, the methodology could increase the efficiency of fighter aviation.

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