TRANSPORT PROBLEMS 2018 Volume 13 Issue 2
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2018.13.2.3

Keywords: fuzzy logic; fuzzy expert system; helicopter take off

Marlena MENDREK, Norbert GRZESIK*, Aneta KRZYŻAK, Konrad KUŹMA
Dęblin Air Force Academy, Department of Aviation
303 Dywizjon Street, no. 35, 08-521, Dęblin, Poland
**Corresponding author*. e-mail: n.grzesik@wsosp.pl

DIFFERENT DEFUZZIFICATION METHODS IN GUIMBAL CABRI G2 HELICOPTER TAKEOFF POSSIBILITY EVALUATION

Summary. The article discusses the aerodynamic properties of the Guimbal Cabri G2 helicopter. The main considerations concern the helicopters ascending to the altitude under initial conditions, which were assumed in the project and how the change of the defuzzification method affects the work of the fuzzy controller. The authors analyzed the following: the aircraft, the crew and the payload. The authors assessed the altitude and the minimum time of the helicopter climb. In designing and the work simulation process, the authors used Matlab and Simulink software. A comparison of the influence of selected defuzzification methods on the work of the fuzzy controller was made.

1. INTRODUCTION

There are a lot of international publications concerning the use of fuzzy logic in the real world [5, 9, 16], but limited in aviation (in general). Some of them describe aircraft control systems [3, 6, 8, 11, 14, 18] and some aircraft safety issues [3, 12, 13, 15, 19]. There are also works related to the use of fuzzy logic to stabilize the helicopter flight [17] or to give desired horizontal velocity and to regulate the attitude angles, so that the helicopter achieves its desired horizontal velocities at the desired altitude [10].

Guimbal Cabri G2 (Fig. 1) is a two-seat light single-engine helicopter manufactured by the French company, Helicopteres Guimbal. Thanks to its auto-rotation properties, it is ranked among the safest helicopters worldwide. It was certified in accordance with the strictest construction standards, CS-27, which until now have been met only by much larger and more expensive aircrafts. Thanks to the spacious cabin, low-operating costs and a large display of engine parameters of the Cabri G2, it is not only ideal for training inexperienced pilots, but also it proves excellent for tourist flights, as well as flights on demand. This helicopter is backed up by its experience in training pilots in ten countries around the world including Germany, Switzerland, Australia and New Zealand. Currently, it is being used in Dęblin.

The rotorcraft is powered by a piston engine manufactured by Lyocoming with an electronic ignition system and a digital power regulator of nominal power, 180 KM reduced to 145 KM. The Cabri G2 is standard-equipped with modern avionics system Garmin GTM650. In place of a conventional tail rotor system, the designers used a Fenestron, which improves the performance, security, as well as enhancing the handling of the helicopter. Cabri G2 features a composite structure that provides extra security in the event of a hard landing [1].

Table 1

Guimbal Cabri G2 technical parameters

Name	**Parameter**
Engine	Lycoming O-360 145 KM
Maximum Takeoff Weight	700 kg
Empty weight	420 kg
Max Cruising Speed	100 kt
Cruising Speed at 85% thrust	90 kt
Velocity Never Exceeded	130 kt
Hover Ceiling at Max Weight (IGE)	5000 ft
Range (with 15 min. final reserve fuel)	700 km
Maximum endurance with two crew members	4,4 hr

Fig. 1. Guimbal Cabri G2 (Photo by Peter von Reichenberg, www.fotostyle.cz (c) 2012)

2. THE FUZZY EXPERT SYSTEM DESIGN FOR THE EVALUATION OF THE HELICOPTER ASCENDING

In the design, we used the MATLAB software. The system was designed by means of:

1) "Fuzzy Logic Toolbox”;
2) "Simulink”.

The design of the system was initiated by determining the input parameters, which were called:

- helicopter weight,
- crew weight,
- cargo weight.

Each input signal is described by three Gaussian membership functions expressed in kilograms (Figs. 2 - 4).

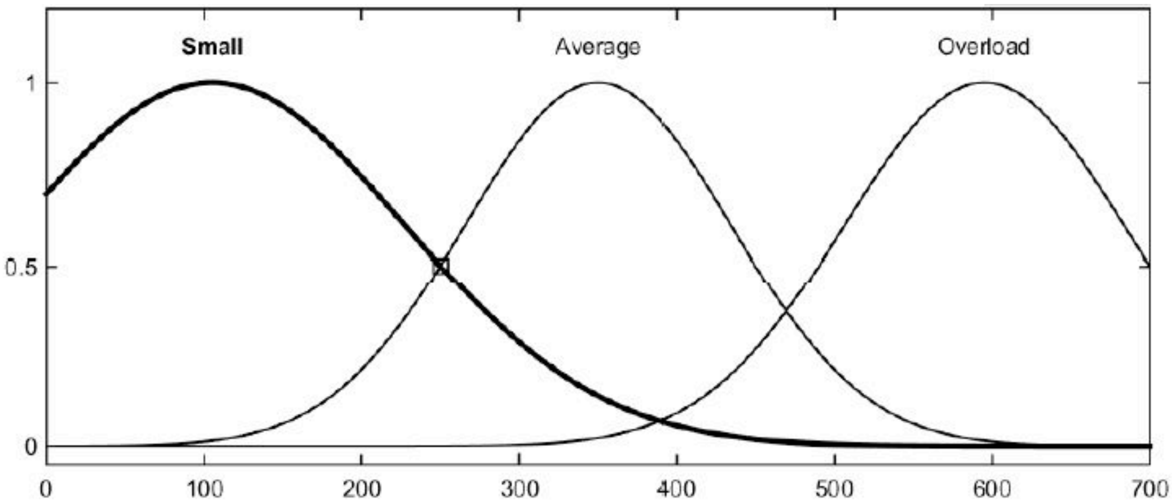


Fig. 2. Membership function for input signal 1, "helicopter weight” [kg]

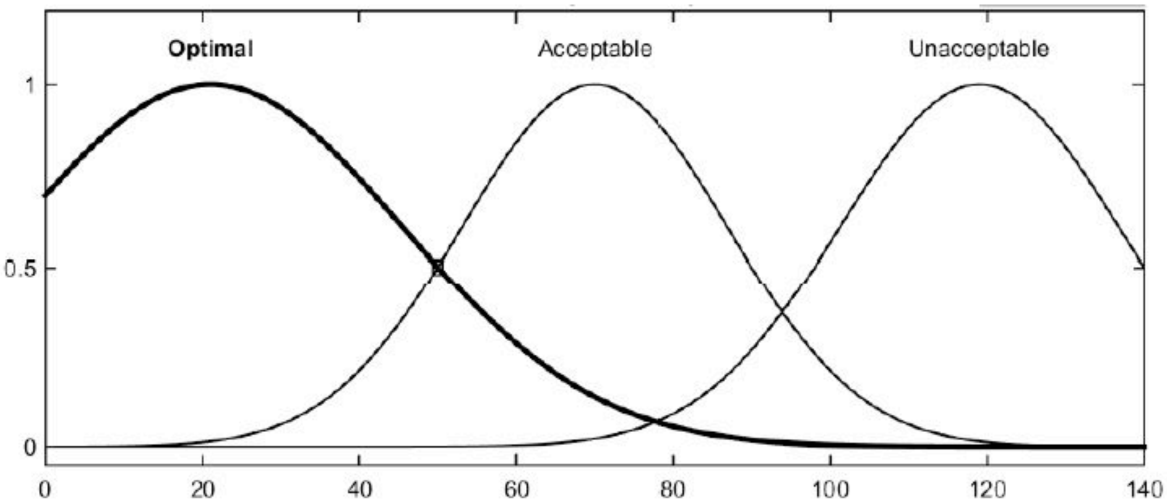


Fig. 3. Membership function for input signal 2,"crew weight” [kg]

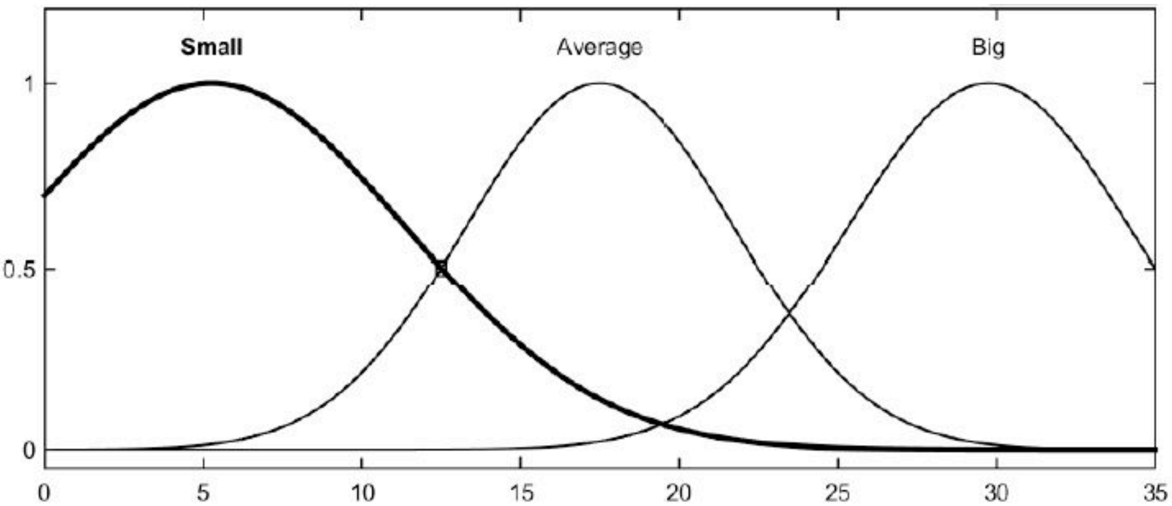


Fig. 4. Membership function for input signal 3"cargo weight” [kg]

The first output signal (Fig. 5) is the altitude achievable by the aircraft. We considered the range of 0– 1,400 ft, which corresponds to the altitudes at which the examined helicopter executes each type of mission (training, tourist, or special flights, most frequently en-route flights).

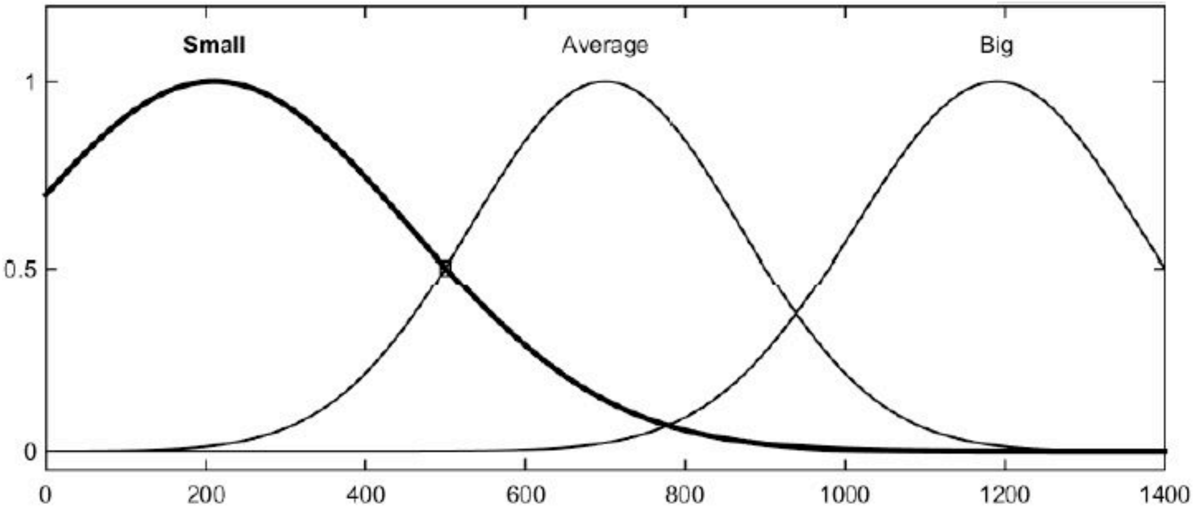


Fig. 5. Membership function for output signal, "ascending altitude” [ft]

The second output signal (Fig. 6) is “climb time” measured in minutes. This is the time in which the helicopter is going to rise to a given altitude. This is a parameter which additionally determines the safety of the executed flights because the crew is able to specify more precisely at which point of the flight it will be on a set-flight altitude.

The climb time was determined in the range of 0–3.5 minutes. We used three Gaussian membership functions, named: slow, average, and fast.

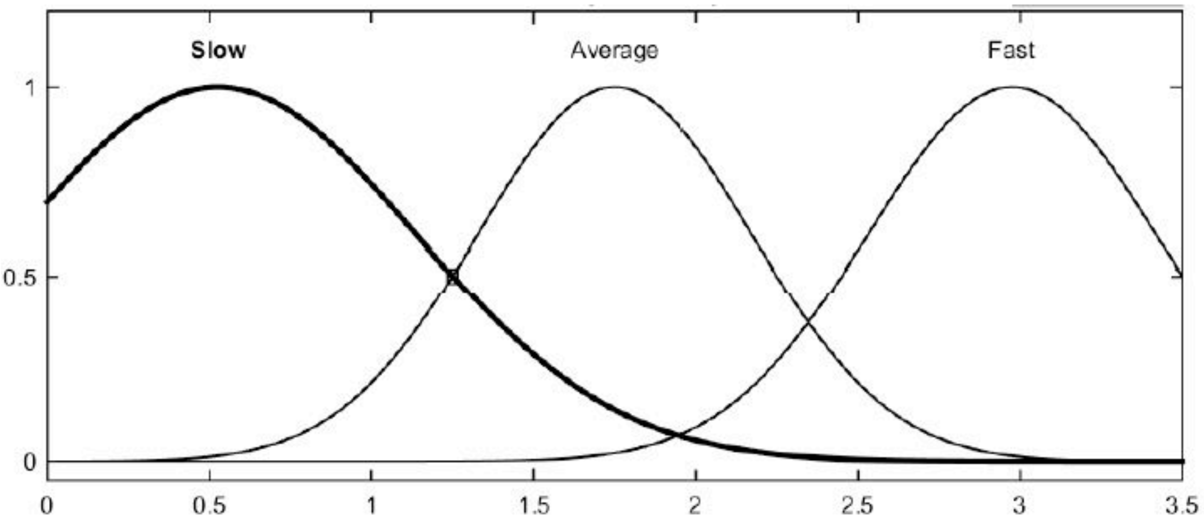
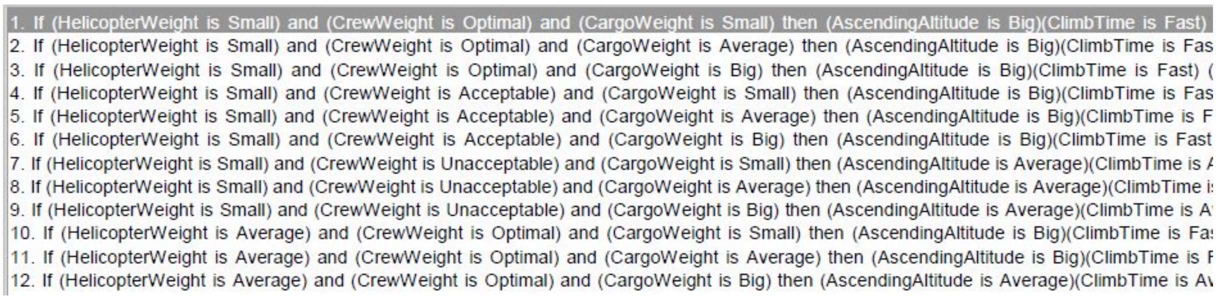


Fig. 6. Membership function for output signal, “climb time”

In order to determine the correct operation of the entire system and the control plane, we established the deduction principles. The principles were based on the initially adopted assumptions. These assumptions are consistent with the principles of aerodynamics and flight dynamics of a helicopter flight [2].

In the deduction principles, we determined the output value of the ascending altitude due to the helicopter weight, the weight of the crew, and the weight of the cargo, which constitute the construction load of the aircraft. To complete the principle base, it was necessary to determine 27 deduction rules. Fig. 7 presents the exemplary deduction rules.

The principle base is made up of deduction rules that specify the manner of work of the designed system. See examples of rules below:



1. If (HelicopterWeight is Small) and (CrewWeight is Optimal) and (CargoWeight is Small) then (AscendingAltitude is Big)(ClimbTime is Fast)
2. If (HelicopterWeight is Small) and (CrewWeight is Optimal) and (CargoWeight is Average) then (AscendingAltitude is Big)(ClimbTime is Fas
3. If (HelicopterWeight is Small) and (CrewWeight is Optimal) and (CargoWeight is Big) then (AscendingAltitude is Big)(ClimbTime is Fast) (
4. If (HelicopterWeight is Small) and (CrewWeight is Acceptable) and (CargoWeight is Small) then (AscendingAltitude is Big)(ClimbTime is Fas
5. If (HelicopterWeight is Small) and (CrewWeight is Acceptable) and (CargoWeight is Average) then (AscendingAltitude is Big)(ClimbTime is F
6. If (HelicopterWeight is Small) and (CrewWeight is Acceptable) and (CargoWeight is Big) then (AscendingAltitude is Big)(ClimbTime is Fast
7. If (HelicopterWeight is Small) and (CrewWeight is Unacceptable) and (CargoWeight is Small) then (AscendingAltitude is Average)(ClimbTime is
8. If (HelicopterWeight is Small) and (CrewWeight is Unacceptable) and (CargoWeight is Average) then (AscendingAltitude is Average)(ClimbTime i
9. If (HelicopterWeight is Small) and (CrewWeight is Unacceptable) and (CargoWeight is Big) then (AscendingAltitude is Average)(ClimbTime is A
10. If (HelicopterWeight is Average) and (CrewWeight is Optimal) and (CargoWeight is Small) then (AscendingAltitude is Big)(ClimbTime is Fa
11. If (HelicopterWeight is Average) and (CrewWeight is Optimal) and (CargoWeight is Average) then (AscendingAltitude is Big)(ClimbTime is F
12. If (HelicopterWeight is Average) and (CrewWeight is Optimal) and (CargoWeight is Big) then (AscendingAltitude is Average)(ClimbTime is A

Fig. 7. Base of selected deduction principles

3. ANALYSIS OF PROPER SYSTEM PERFORMANCE

Having established all the required parameters, we received the control plane (Fig. 8).

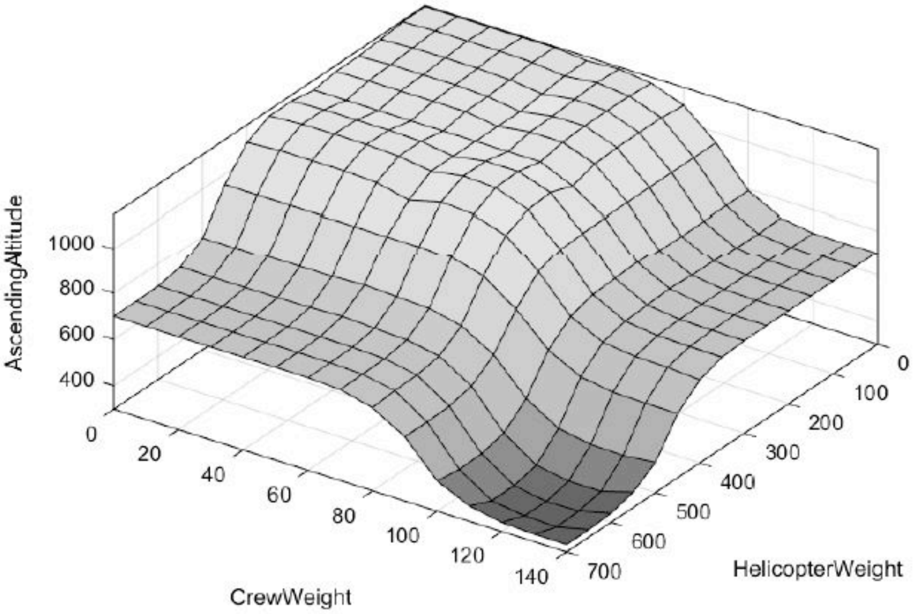


Fig. 8. Control surface

After a thorough analysis of the control surface, it can be concluded that the results of the project are satisfactory with the initial assumptions.

The table below shows the results based on 20 sample data, which were used for the analysis of the programme's performance.

In order to facilitate reading the data contained in the table, we described the data by colors. On the basis of the weight of the helicopter, the crew weight, and payload, as specified in the software, we received the resulting altitude at which the helicopter, Guimbal Cabri G2, is able to rise. The obtained altitude is maintained within the range of 0– 1,400 feet [ft]. The altitude range is as follows:

- Medium altitude: 500–1,000 ft;
- High altitude: 1,000–1,500 ft.

The samples were selected in such a way that each of the obtained altitudes corresponds to a similar number.

Table 2

Research examples for 20 samples

No	Helicopter weight [kg]	Crew weight [kg]	Payload [kg]	Climb altitude [ft]	Time [min]
1	420	60	11	1,103	2.42
2	100	30	5	1,115	2.85
3	112	65	34	1,112	2.80
4	189	22	28	1,080	2.60
5	150	70	5	1,113	2.83
6	170	75	32	1,080	2.69
7	74	120	32	703	1.76
8	200	115	18	709	1.77
9	250	118	5	706	1.77
10	125	116	20	707	1.77
11	350	116	5	701	1.75
12	530	60	18	739	1.83
13	568	22	28	711	1.77
14	700	20	5	700	1.75
15	500	76	32	682	1.04
16	300	115	33	708	1.77
17	540	56	32	700	1.08
18	530	118	32	347	0,87
19	620	128	32	299	0.75
20	568	116	5	317	0.75

By analyzing the results, it is possible to observe that in the optimized system, the load weight of the helicopter also impacts the speed–it rises. The small load of the helicopter, the greater rising altitude is, with time respectively shorter than in the case of excessive load. It is essential to observe the weight standards due to the fact that they affect the quality and efficiency of the executed maneuvers, which are crucial in aviation. In addition, if the maneuvers are more efficiently made, a better air traffic flow is in the air. Time is a relevant factor, therefore the possibility to obtain an accurate estimation of the helicopter's rising time is of valuable advantage to the system.

4. DEFUZZIFICATION METHOD SELECTION ANALYSIS

In this paper, four basic defuzzification methods were compared:

- Center of Gravity (Centroid)
- Center of Sums (Bisector)
- Middle of Maximum (MOM)
- Smallest of Maximum (SOM)

On the basis of the crisp values showed in Table 2, the system calculated the crisp value on output signals using the four defuzzification methods listed above. The control surfaces that were obtained for the results are shown in Fig. 9 to Fig. 12, and the input and output values obtained for 20 research examples is shown in Table 3.

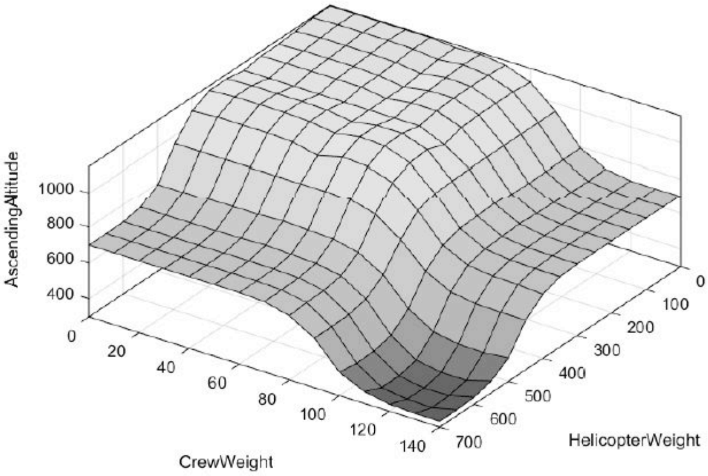


Fig. 9. Control surface – Center of Gravity

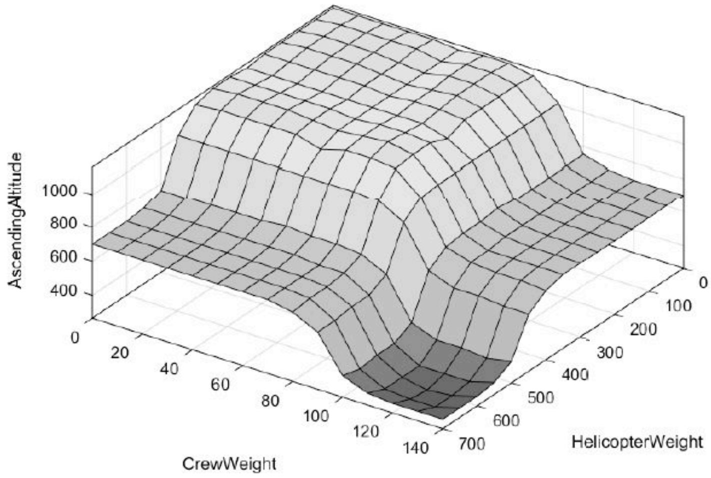


Fig. 10. Control surface – Center of Sums

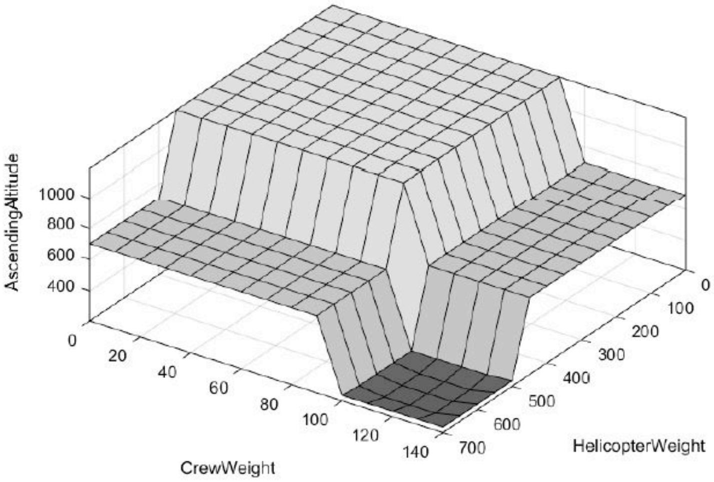


Fig. 11. Control surface – Middle of Maximum

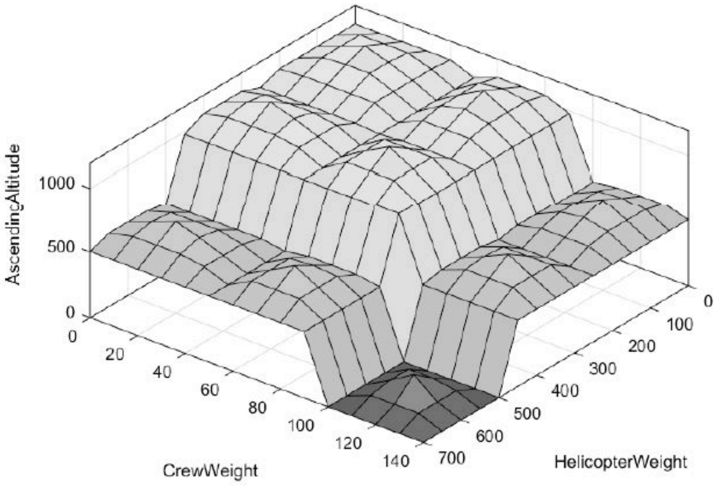


Fig. 12. Control surface – Smallest of Maximum

Table 3

Research examples for 20 samples with different defuzzification methods

No	Input signals			Output signal - altitude			
	Helicopter weight [kg]	Crew weight [kg]	Payload [kg]	Centroid	Bisector	MOM	SOM
1	420	60	11	1,103	1,090	1,119	1,040
2	100	30	5	1,115	1,116	1,119	1,113
3	112	65	34	1,112	1,115	1,119	1,020
4	189	22	28	1,080	1,110	1,119	1,080
5	150	70	5	1,113	1,160	1,119	1,130
6	170	75	32	1,080	1,130	1,119	1,110
7	74	120	32	703	700	700	616
8	200	115	18	709	700	700	574
9	250	118	5	706	700	700	504
10	125	116	20	707	700	700	602
11	350	116	5	701	700	700	672
12	530	60	18	739	714	700	588
13	568	22	28	711	700	700	644
14	700	20	5	700	700	700	504
15	500	76	32	682	686	700	532
16	300	115	33	708	700	700	588
17	540	56	32	700	700	700	560
18	530	118	32	347	308	210	42
19	620	128	32	299	280	210	98
20	568	116	5	317	280	210	140

On the basis of the obtained results, the center of gravity method (centroid), center of sum method (bisector), and middle of maximum method (MOM) gave approximately the same results in the evaluation of the helicopter ascending application. For the smallest of maximum (SOM) approaches, there are wide variations in the results that were obtained. The reason for this is that the method uses the extreme smallest values for calculation of the crisp value.

The comparison shows that the centroid and the bisector methods are better than the MOM and SOM –there is more consistency in the results.

5. THE SYSTEM WORK SIMULATION

The system work simulation was conducted in the *Simulink* software (Fig. 13).

The helicopter weight has a decreasing linear function assigned, as its weight during a flight always decreases as a result of fuel combustion. The crew weight is presented as constant and the cargo weight is presented in an increasing–decreasing linear function [3]. Fig. 14 presents the waveforms of the input signals. The results of simulation are shown in Fig. 15.

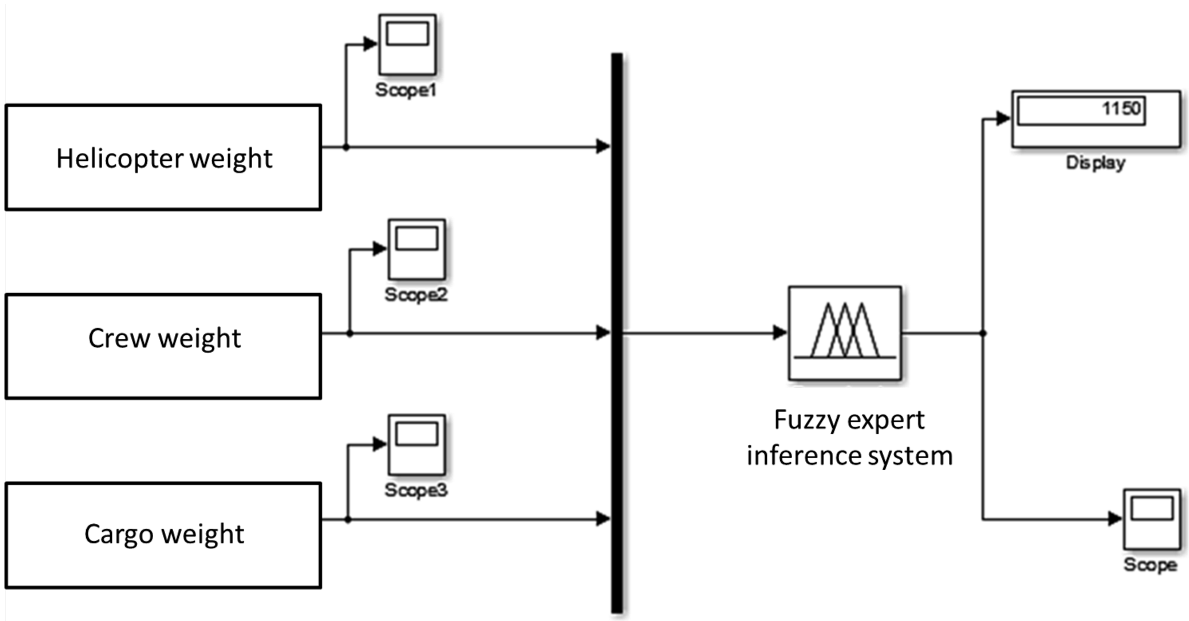


Fig. 13. System project in Simulink software

After the simulation, it was concluded that the project worked properly, because with the helicopter load increasing, the rising altitude diminished. In the graph, it may be deduced that the climb altitude depends on the load of the helicopter: the less it is loaded, the higher is the altitude; and the opposite, the more it is loaded, the lower the altitude it is.

The simulation confirmed the assumption that two methods of defuzzification in the presented project (center of gravity and center of sum) give better results than the other two methods.

6. SUMMARY AND CONCLUSIONS

In the system designing process, the height that is possible to reach by the Guimbal Cabri G2 helicopter in required time was determined. It was obtained with the use of the Matlab software. The input and output values were determined in accordance to the helicopter's, Guimbal Cabri G2, technical instructions. The maximum height of 1,500 [ft] was chosen as the helicopter-cruising altitude or the most frequent flight altitude. However, the duration of helicopter rising was repeatedly measured by a pilot with 30 years of experience and equals approximately 3.5 min on an average. It was also possible to observe during the crew changes, that if the helicopter is under heavier load, it does not climb up so swiftly. This was confirmed by the project and its verification during a flight [4]. Designing a system with an assumed operation was strictly connected to aircraft reliability and safety [7].

In the simulation, the fact that the helicopter while flying consumes fuel, which effects the reduction of its weight, was considered. During the simulation tests, a constant weight of the crew was assumed. The helicopter payload changes due to fuel consumption. However, in real life, during one day of the flight, the crew may change and it affects the whole-helicopter weight.

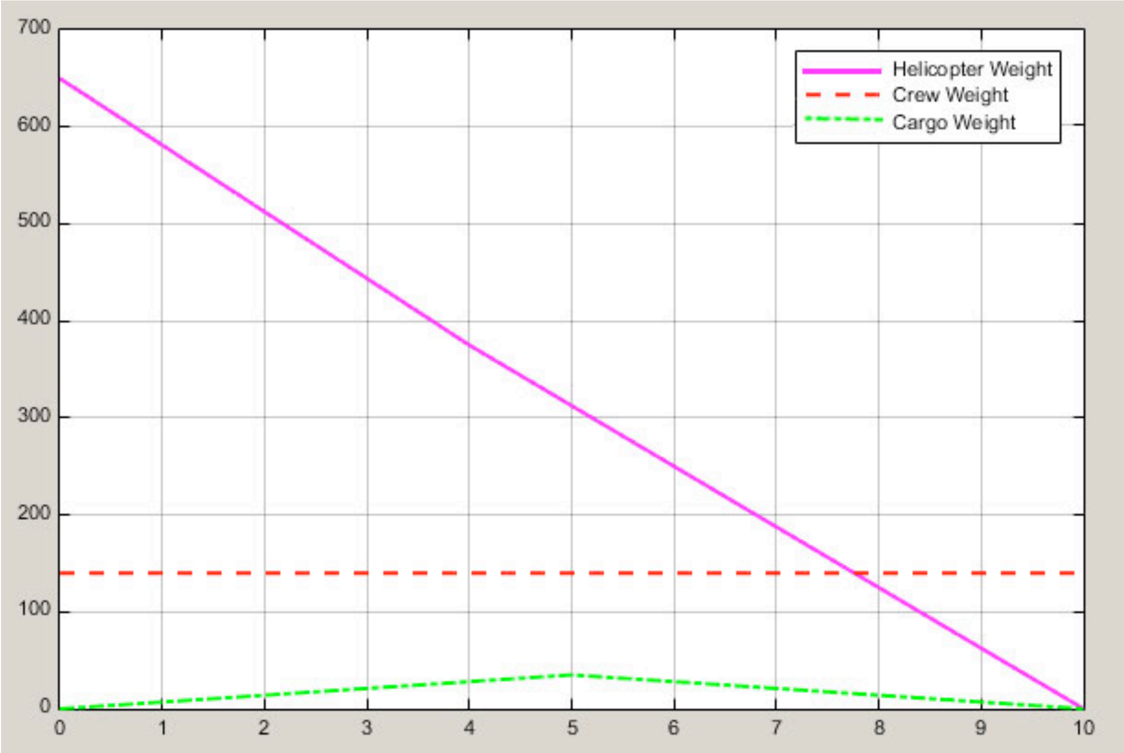


Fig. 14. System project input signals

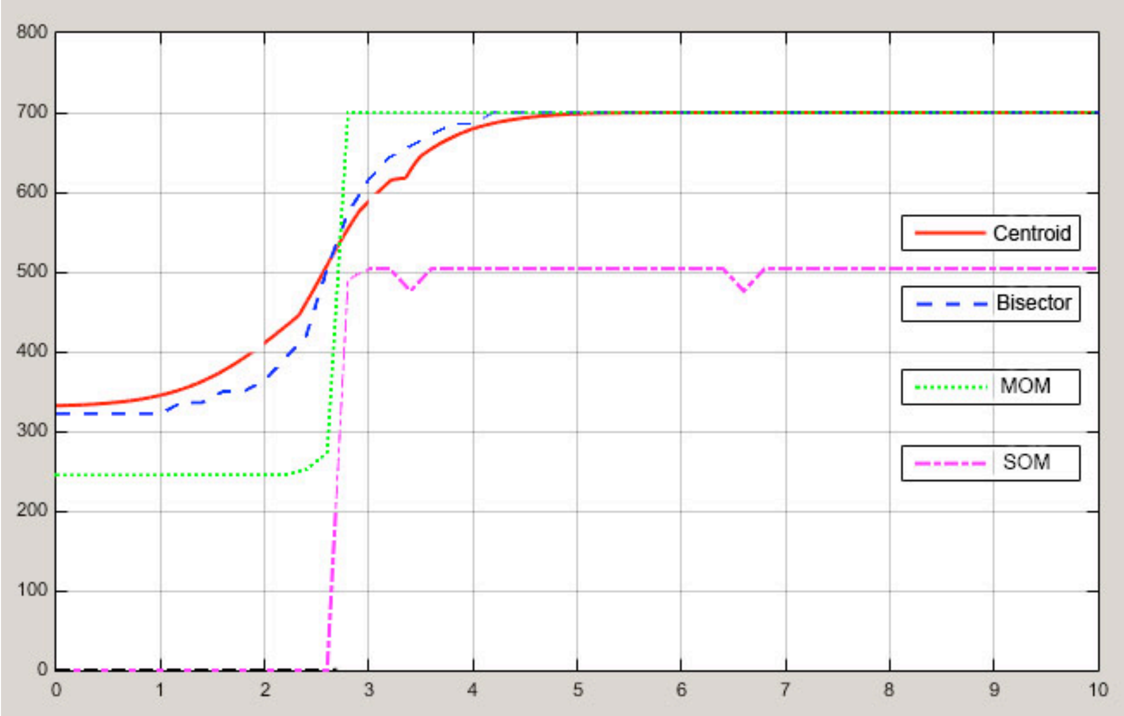


Fig. 15. System project output signal “ascending altitude” for different defuzzification methods

The four methods of defuzzification were analyzed separately according to its influence on the simulation results. The results obtained confirm the supposition that in the designed system the methods centroid and bisector will work better.

References

1. Cabri G2 Flight Manual, EASA Type certificate N^{o} R.145. Guimbal AIX-EN-PROVENCE, FRANCE.
2. Bronowicz, J. *Podstawy aerodynamiki śmigłowca.* Świdnik, 1995. [In Polish: *Basics of helicopter aerodynamics*].
3. Grzesik, N. *Podstawy sterowania rozmytego.* Dęblin. WSOSP. 2012. ISBN 978-83-60908-73-0. [In Polish: *Basics of fuzzy control*].
4. Laskowski, R. *Osiągi, wyważenie i planowanie lotu. Szkolenie samolotowe EASA.* PILEUS. Styczeń, 2014. ISBN 978-83-937468-0-4. [In Polish: *Performance, balance and flight planning. EASA aircraft training*].
5. Anderson, G. *Applying fuzzy logic in the real world*. Reprinted with permission of Sensor magazine. Helmers Publishing. Inc. 1992. Available at: http://www.sensormag.com
6. Doitsidis, L. & Valavanis, K.P. & Tsourveloudis, N.C. & Kontitsis, M. A framework for fuzzy logic based UAV navigation and control. In: *Robotics and Automation. Proceedings*. ICRA '04, Vol. 4. 2004.
7. Jasztal, M. & Żurek, J. & Tomaszek, H. *Prognozowanie uszkodzeń zagrażających bezpieczeństwu lotów statków powietrznych.* ITE Radom. 2008. [In Polish: *Forecasting damages that threaten the safety of aircraft flights*].
8. Luo, J. & Lan, E. Fuzzy Logic Controllers for Aircraft Flight Control. *Fuzzy Logic and Intelligent Systems International Series in Intelligent Technologies.* 1995. Vol. 3. P. 85-124.
9. Kacprzyk, J. & Yager, R.R. Emergency-Oriented expert systems: A fuzzy approach. *Information Sciences*. December, 1985. Vol. 37. Nos. 1–3. P. 143–155.
10. Kadmiry, B. & Driankov, D. Fuzzy control of an autonomous helicopter. In: *IFSA World Congress and 20th NAFIPS International Conference. 2001.*
11. Nho, K. & Agarwal, R.K. Automatic Landing System Design Using Fuzzy Logic. *Journal of Guidance, Control, and Dynamics*. 2000. Vol. 23. No. 2. P. 298-304.
12. Lower, M. & Magott, J. & Skorupski, J. Analiza incydentów lotniczych z zastosowaniem zbiorów rozmytych. *Prace naukowe Politechniki Warszawskiej. Transport.* 2013. No. 100. P. 131-144. [In Polish: Analysis of aviation incidents using fuzzy sets. *Scientific work of the Warsaw University of Technology. Transport*].
13. Hadjimichael, M. A fuzzy expert system for aviation risk assessment. *Expert Systems with Applications.* 2009. Vol. 36. No. 3. Part 2. P. 6512-6519.
14. Wahid, N. & Rahmat, M.F. Pitch Control System Using LQR and Fuzzy Controller. In: *IEEE Symposium on Industrial Electronics and Applications (ISIEA 2010)*. Penang, Malaysia. 2010. P. 389-394.
15. Demirci S. & Hajiyev, CH & Schwenke, A. Fuzzy logic based automated engine health monitoring for commercial aircraft. *Aircraft Engineering and Aerospace Technology*. 2008. Vol. 80. No. 5. P. 516-525.
16. Chaudhari, S. & Patil, M. Study and Review of Fuzzy Inference Systems for Decision Making and Control. *American International Journal of Research in Science, Technology, Engineering & Mathematics.* December 2013-February 2014. Vol. 5(1). P. 88-92.
17. Tanaka, K. & Ohtake, H. & Wang, H.O. A practical design approach to stabilization of a 3-DOF RC helicopter. *IEEE transactions on control systems technology*. 2004. Vol. 12(2). P. 315-325.

18. Usta, M.A. & Akyazi, O. & Akpinar, A.S. Aircraft roll control system using LQR and fuzzy logic controller. *Innovations in Intelligent Systems and Applications (INISTA)*. 2011. DOI: 10.1109/INISTA.2011.5946069.
19. Żurek, J. & Grzesik, N. Fuzzy expert aircraft onboard control systems assistant. *Safety reliability and risk analysis: Beyond the horizon. ESREL conference proceedings*. London: Taylor & Francis Group. 2013. P. 250-251.

Received 03.12.2016; accepted in revised form 04.06.2018