

# Simulation of Activities of Helicopter Flight Crews in Emergency Situations



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## ABSTRACT

*Flight safety assurance problems solving focuses on aviation systems of different size as the objects of the study. Flight safety theory addresses such subjects of the study as operation of a specific aviation system «crew-aircraft» (C-A), detection and evaluation of hazards, as well as their localization or elimination.*

*Protective features of «crew-aircraft» aviation system should provide resistance to occurrence of abnormal cases. Aviation practices show that the protective features of the system are not always able to prevent development of danger, and a catastrophe becomes the most likely outcome of a flight.*

*When encountering such abnormal cases, the crew must use rescue equipment in order to reduce severity of the aviation accident and to prevent their own death. The article presents the results of network modelling of the pilot's activity algorithm and of determining the probability of timely forced escape from of a helicopter with a rescue parachute.*

*The objective of the study is to assess effectiveness of protective features of C-A system in helicopters with the aim to reduce severity of aircraft accidents. To test the hypothesis about the possibility of using rescue equipment by helicopter crews, probabilistic statistical as well as experimental and calculation research methods were used.*

***Keywords:** transport, aviation, helicopters, emergency, rescue equipment, parachute system, probability, algorithm.*

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**Background.** Since the beginning of 21<sup>st</sup> century, the aviation standards [1, 2] governing flight safety management systems have actively used the concept of «acceptable risk» based on a probabilistic approach. However, the use of probabilistic and statistical methods for assessing safety of functioning of the aviation system is a privilege for specialists in accident and incident investigations, and that certainly affects the process of ensuring systemic safety by aircraft operators. The analysis of causes of large number of aviation accidents and incidents that occurred with helicopters, comprising civil helicopters, showed that the traditional methodology for training flight crews for operations in abnormal cases does not fully meet modern requirements. The relevance of research is due to the need to train aviation specialists in risk assessment methods to identify hazards and severity of the consequences during the operation of aircrafts.

**Objective.** The objective of the study is to assess effectiveness of protective features of C—A system in helicopters with the aim to reduce severity of aircraft accidents.

**Methods.** To test the hypothesis about the possibility of using rescue equipment by helicopter crews, probabilistic statistical as well as experimental and calculation research methods were used.

#### **Results.**

The work of A. G. Agronik and L. I. Erenburg notes that «...the study of statistical materials on accidents led foreign experts to a solution indicating that the possibility of using emergency escape equipment in helicopters is limited by the features of its combat use at extremely low altitudes and comparatively high speeds, as well as by a difficulty for a pilot to make a decision to escape» [3, p. 168]. Indeed, as a result of the active use of US aviation in Vietnam (1964–1975), 5 607 helicopters were lost, the total number of deceased pilots exceeded two thousand people [4], and that was the reason for implementation of the ideas of shock protection of helicopter crews.

The study of design features of helicopters of leading Western manufacturers like Airbus Helicopters, Boeing, Sikorsky Aircraft Corporation, Leonardo (Augusta Westland), Bell Helicopter showed that passive protection systems based on the use of special devices that

absorb impact energy during emergency landing are the most effective means of saving the flight crew. The basic principles for ensuring survival of helicopter crews are described in the work of D. F. Shanahan [5].

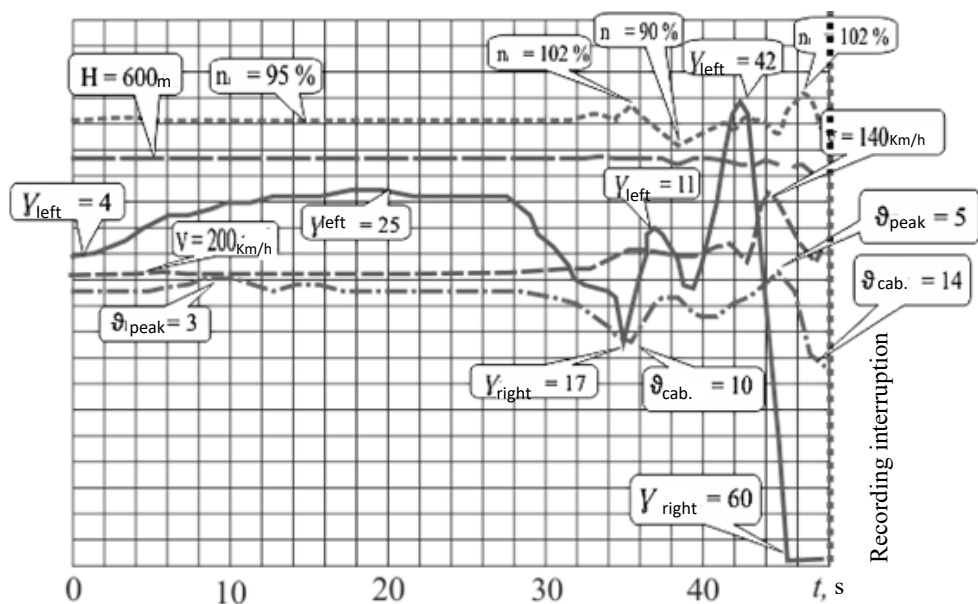
The main causes of losses of helicopter crews in the event of an accident were named, they are: shock loading (excessive acceleration); direct injury from contact with hard surfaces; impact of external environmental factors after emergency landing (fire and combustion products, water, harmful and toxic substances, etc.). Therefore, effective aircraft design should have a set of properties that can protect the crew and passengers against the effects of possible sources of injury both during emergency landing and against its negative consequences [6–9].

UH-60 Black Hawk and AH-64 Apache helicopters have shock absorption struts with two-stage shock absorption, which can reduce impact by up to 60 % and ensure crew survival during landing at a speed of up to 12,8 m/s. After that shock loading is absorbed due to energy absorbing devices of seats and deformation of the helicopter structure. Fastening elements of power units prevent displacement of engines and the main gearbox into the interior of the fuselage when the helicopter hits the ground. The fuel system is characterized by increased survivability. Automatic pipe sealing reduces a risk of fire. The structural elements of the helicopter chassis are put away from the fuel tanks and, when they hit the ground, do not penetrate the fuselage. Currently, the issue of equipping helicopter cabins with airbags is being actively considered.

An analysis of existing onboard crew rescue systems of domestic helicopters indicates that, along with equipment of certain types of aircraft with shockproof protection systems [10; 11], rescue parachute systems (PS) are still in operation.

The effectiveness of aircraft emergency escape is determined by a number of random variables, the calculations of which are performed using probability theory and mathematical statistics. It has been established that the efficiency of using rescue equipment can be most comprehensively assessed through the index of probability of rescuing a pilot in emergency situation [12] that can be determined by the formula:





**Pic. 1. Fragment of the APRA software recording of the accident with Mi-8 helicopter (destruction of the tail rotor drive).**

$$W_{\text{resc}} = W \cdot P_{\text{use}}, \quad (1)$$

where  $W$  – probability of rescue of a pilot when using rescue equipment;

$P_{\text{use}}$  – probability of using rescue equipment in an emergency situation.

The probability of rescue  $W$  can be represented as a function:

$$W = \begin{cases} f[v, v_y, H, \gamma, \theta, \omega_x, \omega_y, \omega_z, n_y] \\ f[v_0, t_s, u, p, A], \end{cases} \quad (2)$$

where  $v, v_y, \gamma, H, \theta, n_y$  – distribution functions of the helicopter flight parameters (horizontal and vertical components), roll, pitch, flight altitude;

$\omega_x, \omega_y, \omega_z$  – angular speeds of rotation in all projections;

$n_y$  – effect of normal overload on an aircraft and on a pilot in the event of an emergency situation; distribution function of fall parameters of a pilot's body,

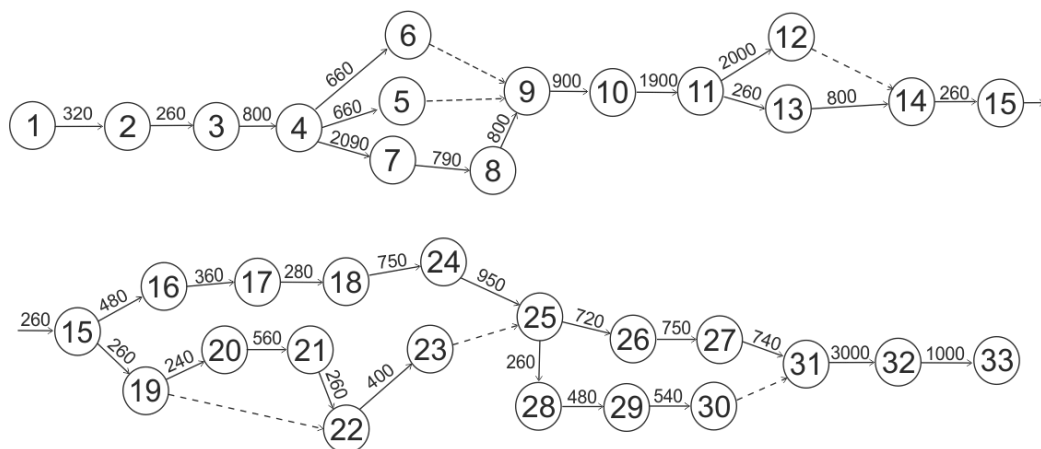


Table 1

**Temporal characteristics of the activities of a crew commander of the Mi-8 helicopter  
in an abnormal situation (destruction of a tail rotor drive)**

Operation code	Content of operation (job)	$\bar{\tau}_j$ , ms	$\sigma_{\tau}$ , ms
1–2	Perception of a vestibular signal (stimulus) from evolution of a helicopter	320	30
2–3	Transfer of sight to the outside of the cabin	260	30
3–4	Assessment of spatial position and decision making on elimination of deviations of a helicopter	800	120
4–5	Moving collective pitch lever down	660	50
4–6	Tilt a control handle to the left and toward a pilot	660	70
4–7	Reading and perception of instrument readings	2090	150
7–8	Search, detection and perception of «Failure» light-signal board	790	50
8–9	Assessment of information and highlighting a set of informative features	800	280
9–10	Activation of pre-memorized signal about the current situation	900	390
10–11	Formation of a conceptual model of activity and decision-making on escape from a helicopter	1900	650
11–12	Submission of a command for forced escape (4–5 words)	2000	1200
11–13	Transfer of sight to the outside of the cabin	260	30
13–14	Assessment of the spatial position of a helicopter	800	70
14–15	Transfer of sight to the reset handle of the left blister	260	30
15–16	Transfer the left hand from collective pitch lever to the blister reset handle	480	50
16–17	With the left hand, pull out the emergency blister relief handle	360	50
17–18	Lean with your left hand in the lower left corner of the opening	280	30
15–19	Transfer of sight to the seat belt lock	260	30
19–20	Transfer the right hand from control lever to the seat belt lock	240	30
20–21	Open the lock of the seat belts with your right hand	560	70
21–22	Transfer of sight to a semi-soft loop	260	30
22–23	With your right hand, grasp the semi-soft loop in the upper opening of the blister	400	30
18–24	Take out the right foot into the aisle between the seats	750	100
24–25	Get up, take the parachute out of the seat bucket	950	300
25–26	Turn left towards the opening; rotate the body 90°	720	70
26–27	Place the left foot on the seat bucket	750	250
25–28	Transfer of sight to the indicator of true altitude	260	30
28–29	Reading altimeter	480	70
29–30	Control of escape by crew members	540	150
27–31	By the push of both legs with simultaneous movement of the arms towards oneself to separate from a helicopter	740	200
31–32	Pulling out the release ring	3000	500
32–33	Parachute opening	1000	100





**Pic. 2. A network model of the crew commander's activity during destruction of the tail rotor drive and forced escape from Mi-8 helicopter.**

$v_0$  – initial speed when leaving a helicopter;  
 $t_s$  – time of pilot's body stay in a range of reach of blades of helicopter's main rotor;  
 $u$  – horizontal component of pilot's fall speed;

$p$  – tangent of incidence angle;

$A$  – value of removal from an initial point of separation from a helicopter.

The criteria for probability of using PS are temporal characteristics of actions of a pilot (operator) in case of emergency:

$P_{use} = f[t_{req}, t_{lim}, \tau_{op}]$ , (3)  
 where  $t_{req}$ ,  $t_{lim}$  – respectively, required and limited (available) time to prevent catastrophic consequences of an emergency situation;

$\tau_{op}$  – speed of reaction of a human operator.

The required time to perform the necessary actions is determined by the expression:

$t_{req} = t_{det} + t_{as} + t_{dm} + t_{pr}$ , (4)  
 where  $t_{det}$  – time of detection of perception and decoding of information;

$t_{as}$  – time of assessment and processing of information;

$t_{dm}$  – formation of a conceptual model of activity and decision making;

$t_{pr}$  – time for practical implementation of the decision made.

The determination of available time necessary for implementation of actions aimed at the application of PS depends on a large number of factors in each specific emergency situation. Long-term observations have led to the conclusion that catastrophic consequences in helicopters are caused by: transmission failures (main, intermediate and tail gears); damage to the main and tail rotors; failure of the main and backup hydraulic

systems; destruction of control system elements. The development of abnormal situations occurs transiently and requires the immediate use of parachute systems to rescue crews if the altitude allows the use of PS.

To develop a model of activity of a helicopter crew member in the event of an emergency and the use of PS, we will use the network method [13, 14].

It is possible to predict and to determine the likelihood of timely execution of actions for forced escape from a helicopter in the presence of a given standard  $t_{lim}$ , using the expression:

$$q(t) = P\{\tau_{op} \leq t\} = \int_0^t f(\tau) d\tau, \quad (5)$$

where  $t = t_{lim}$  – normatively determined available time for execution of actions.

The activities of a pilot are divided into elementary operations [15; 16]. When performing network modelling, they are called jobs, and the moments of their completion are called events. Each operation is characterized by a mathematical expectation and dispersion of duration of work. Given the independence of individual operations, the speed of reaction  $\sigma_{op}$  is characterized by parameters subject to the normal distribution law:

$$\bar{\tau}_{op} = \sum_{ij} \bar{\tau}_{ij}; \quad \sigma_{\tau} = \sqrt{\sum_{ij} \sigma_{ij}^2}, \quad (6)$$

where  $\bar{\tau}_{op}$  and  $\sigma_{\tau}$  – respectively, mathematical expectation and variance of duration of operations.

The total execution time of the task of helicopter forced escape is equal to the sum of duration of operations or the critical path (algorithm) of  $L_i$  network model:

$$\tau_{op} = \max L_i. \quad (7)$$

To conduct simulation, activity of a crew commander of Mi-8 helicopter was chosen in the event of an abnormal flight situation related to destruction of the tail rotor drive. It is assumed that a flight mission is performed according to the rules of visual flight (VFR), at the altitude of at least 500 m. The operations performed by a pilot are error-free. The sequence of operations and their temporal characteristics are presented in Table 1.

The initial signs characterizing destruction of a tail rotor in flight are associated with the changes of the attitude of a helicopter in space. The aircraft turns sharply to the left, changes in roll and pitch angles reach their limit values in a short time (Pic. 1).

The initial reaction of a pilot in command is, as a rule, an intuitive desire to restore the spatial position of the helicopter by acting on control devices (operations 4–5, 4–6). The developed network model (Pic. 2) takes into account the series-parallel nature of performance of individual sensory-motor, motor and logical operations.

Operations (25–28, 28–29) are necessary to determine the true altitude of leaving the helicopter and to withstand time in free fall until the PS is opened. The critical path for the model is described as 1–2, 2–3, 3–4, 4–7, 7–8, 8–9, 9–10, 10–11, 11–13, 13–14, 14–15, 15–19, 19–20, 21–22, 22–23, 18–24, 24–25, 25–26, 26–27, 27–31.

The movement of the body after leaving the helicopter (31–32) and opening of the parachute (32–33) are not taken into account in duration of the pilot's activity.

The probability of using PS is determined by the expression:

$$P_{pr} = P\{\tau_{op} \leq t_{lim}\} = \int_0^{t_{lim}} f(\tau) d\tau = F_0\left(\frac{\bar{\tau}_{op}}{\sigma_{\tau}}\right) + F_0\left(\frac{t_{lim} - \bar{\tau}_{op}}{\sigma_{\tau}}\right), \quad (8)$$

where  $t_{lim}$  – standard time for execution of the algorithm of actions. The standards of simulator training were used to assess the actions of a pilot in abnormal situations in flight [15].

The probability of timely helicopter escape at a set limit  $t_{lim} = 15$  s will be  $P_t = 52$  %. If the time limit will be extended to 20 s, then the probability of using PS will respectively increase to 96 %.

**Conclusions.** The studies and the network model of the pilot's activity in the event of an emergency make it possible to more accurately determine the rescue methods for helicopter flight crews in order to reduce severity of

aircraft accidents. It is so possible to further develop rational methodological methods of training of flight crews to counter emergency.

To justify the probability of rescue of flight crews, a universal mathematical model is required that takes into account the dynamics of all the objects involved (helicopter, pilot, PS) in emergency situations.

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