THE INFLUENCE OF BIOMECHANICAL PROPERTY OF PILOT (CREW) ON PROBABILITY OF AIR-CRASH

WPŁYW BIOMECHANICZNYCH WŁASNOŚCI PILOTA (ZAŁOGI) NA PRAWDOPODOBIEŃSTWO WYSTĄPIENIE KATASTROFY LOTNICZEJ

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Abstract: Article presents aspects concerning the correlation between probability (P_Z) of loosing airworthiness of helicopter and probability (P_E) of pilots and crew mistake during difficult landing manoeuvre. This allows to calculate the area of the reduced probability (P_K) of air crash.

The aim is to define probability (P_Z) as damage resistant parameter of helicopter and probability (P_E) of pilot and staff mistake taking into account their assessment (scale of Coopera-Harpera) in making very hard manoeuvre.

That is why the influence of biomechanical characteristics of pilot (crew) is very important to determine the probability of air accident

Keywords: *biomechanics, survivability, decision process of pilot (crew), aircraft safety*

Streszczenie: W artykule podjęto tematykę dotyczącą wyznaczenia korelacji pomiędzy prawdopodobieństwem (P_Z) utraty własności lotnych śmigłowca a prawdopodobieństwem (P_E) pomyłki pilota i załogi podczas wykonywaniu bardzo trudnego pilotażowego manewru lądowania, co pozwoliło na wyznaczenie obszaru o zmniejszonym prawdopodobieństwie (P_K) wystąpienia katastrofy lotniczej.

W tym celu wyznaczono prawdopodobieństwa (P_Z) jako parametr odporności śmigłowca na uszkodzenia oraz prawdopodobieństwo (P_E) pomyłki pilota i załogi z uwzględnieniem ich oceny (wg skali oceny Coopera-Harpera) w fazie podejścia do lądowania, jako jeden z trudniejszych elementów lotu.

Uzasadnione jest zatem rozpatrywanie zagadnienia dotyczącego wpływu biomechanicznych własności pilota (załogi) na prawdopodobieństwo wystąpienia katastrofy lotniczej.

Słowa kluczowe: *biomechanika, żywotność, proces decyzyjny pilota (załogi), bezpieczeństwo lotu*

1. Introduction

The base of aviation developing needs a big pressure on safety and effectiveness of helicopters flight by producers and users. The damages often are the reasons of aviation accidents during operation of helicopters. Moreover the stoppages due to helicopters breakdown influence flight reliability. The reliability determines the following aspects:

- threaten of pilot and crew lives;
- loss of helicopters;
- cost of contaminated area utilization [19].

The helicopter survivability problem in biomechanical characteristic aspect of pilot (crew) is important for the safety of aircraft.

The maintenance and operation of helicopter should provide:

- safety of pilot and crew;
- task realization during flight;
- optimization of costs of maintenance and operation;
- the smallest, negative effect on environment;
- the suitable survivability which allows to fly even after damage.

The data related to the reasons of aviation accidents during last 30 years according to ICAO (International Civil Aviation Organization) is showed in table 1.

Table 1 The reasons of aviation accidents based on ICAO

The reason of accident	The number of accidents [%]	
	Land transport	Air transport
The human mistake	40-50	80
The technical damage	10-30	10
The environmental influence	8-10	5
The others (no explanation)	5-10	5

According to ICAO the majority of aviation accident are caused by human mistakes. One of the methods to solve the problem concerning the correct performance of the air task is to define the influence of helicopter's survivability on the decisional process of pilot (crew).

Particularly, this matters to assure the reliability for:

- the safety of flights;
- the regularity of flights;

- the technical readiness;
- the effectiveness of the management in the operational process;
- the economy of the operational process

The number of air accident losses can be decreased by creating the decisional model of pilot in the sphere helicopter survivability prevention. The decisional model describes the features of pilots (physical condition factors with predispositions for high level flying).

Moreover decisional model of pilot enables to make rapid decisions at the time of damage appearance during flight. Taking under consideration this aspect, there can be defined the correlation between survivability (resistance to damage) and the range of the time to make decision by pilot. It means that if the level of survivability is higher then there is more time for pilot's decision. The publication presents the aspect concerning the influence of biomechanical property of pilot (crew) on probability of air-crash.

2. Probability of helicopter's survivability

The assessment of helicopter's survivability is made on the basis of the analysis of proportional share of the damages which emerged as a result of improper maintenance and operation and also because of the changing weather conditions during the flight.

Helicopter is airworthy at a moment (t), when following conditions are fulfilled [8]:

$$C_0(t) \geq W_0, \Delta Z(t) \geq \Delta Z_{\min} \quad (1)$$

where:

C_0 - set of helicopter's characteristics (attributes) to perform the task at a moment (t);

W_0 - set of basic operating conditions for the helicopter's flight protection;

$\Delta Z(t)$ - number of helicopter's flights from the moment (t) to the resource depletion, the operating materials (fuel, oil, etc.);

$\Delta Z_{\min}$ - minimal, indispensable operating material resource for the helicopter's flight protection.

The necessary and sufficient condition for flight safety is the correlation between technical and flying features of helicopter and its airworthiness in the disposable time (t_D), which doesn't exceed the time of survivability (t_Z).

$$\left\{ \begin{array}{l} C_0(t_D) \geq W_0 \\ \Delta Z(t_D) \geq \Delta Z_{\min} \end{array} \right\} \leq t_Z \quad (2)$$

This relation allowed to assess the helicopter's survivability (figure 1).

Fig. 1 Assessment of helicopter's survivability

Entourage interaction (entry) appears in the form of the indirect and direct operating influence.

The staff guiding the air-traffic influences the indirect operation, however the handling characteristics and handling proceedings of technical staff influences the direct operation.

Moreover the direct operation is also influenced by:

- weather factors (fog, rain, icing, lightning ,etc.);
- environmental factors (crash with a bird, foreign bodies, etc.).

The helicopter's influence on the environment (useful and useless exit) concerns:

- the influence of the damage on handling performance, which can cause the air-accident;
- the influence in the acoustical, thermal and light capacity;
- the influence in the form of used additional substances e.g. exhaust fumes.

The phenomenon of conversion from the useless state during the flight will occur with a different frequency depending on the intensity of helicopter's influence on the environment.

So the irreversible changes in a helicopter are defined as the probability (Q) of the damage during the n flights, and we can write it as [8]:

$$Q_n = Q + (1-Q)Q + 1(1+Q)^2 + \dots + (1-Q)^{n-1}Q \quad (3)$$

We make a conversion:

$$Q_n = Q[1 + (1-Q)Q + 1(1+Q)^2 + \dots + (1-Q)^{n-1}] \quad (4)$$

The formula for the sum of n flight in the geometrical progression is following:

$$\sigma_n = \frac{(1 - (1 - Q)^n)}{1 - (1 - Q)} \quad (5)$$

So:

$$Q_n = \frac{Q[1 - (1 - Q)^n]}{Q} = 1 - (1 - Q)^n \quad (6)$$

This relation defines the probability (Q) of the damage during n flights.

From the asymmetrical relations we can observe that when the number of flights (the number of working hours) $\rightarrow \infty$ then the probability of the damage is: $Q_\infty = 1$.

Taking under consideration the reliability of helicopter, which should perform the appropriate maximal number of n flights fixed by the producer, the average run of helicopter ($\bar{n}$) can be defined by using the formula (9), what allows to define survivability:

$$\bar{n} = \frac{1 - (1 - Q)^n}{Q} \quad (7)$$

where:

$\bar{n}$ - average run of combat helicopter;

Q – probability of the damage;

n – number of working hours.

Fixing the average run $\bar{n}$ and the average time of survivability $\bar{t}_Z$ in compliance with the number of damages refer to the determination of the factor of helicopter's resistance to damages in the form of the probability (P_Z) [2]:

$$P_Z = 1 - \frac{\bar{n}}{\bar{n} + \bar{t}_Z} \quad (8)$$

where:

$\bar{n}$ - average run of helicopter [hours];

$\bar{t}_Z$ - average time of liveliness in a defined time interval [hours].

The defined probability (P_Z) allows to assess the helicopter's survivability, so to present its resistance and durability against damages caused by the

improper operation by the crew and by the improper service by the technical staff in the changing environmental conditions e.g.: icing, big gradient of temperatures changes, humidity and atmospheric pressure, lightning, turbulences etc.

To define the helicopter's flight safety we have the probability (P_Z):

Table 2

Factor	Helicopter 1	Helicopter 2	Helicopter 3	Helicopter 4
Probability P_Z (according to the formula 8)	0,49	0,44	0,47	0,43

During defining the average time of survivability $\bar{t}_Z$ we can't limit only to the experts' evaluation but we should also use the present data included in publications, instruction manuals for the type of helicopter. Data collection to define the probability (P_Z) is the laborious process, nevertheless it is very useful to fix the resistance to damages and the level of helicopter's reliability.

This allows also to define the safety indicator during the flight, what can be the essential information when we choose and buy a certain type of helicopter (fig. 2).

Fig. 5 The safety of comparable helicopters on the basis of the probability (P_Z)

3. The safety of flight and the biomechanical characteristic of helicopter's pilot (crew)

The statistics of air-crashes (table 1) point that the human mistakes take the significant part in them. Dangers caused by the pilot's mistakes are only partly possible to assess and forecast especially in some untypical and stressful situations.

However the requirements concerning the flying equipment, its liveliness and resistance to damages are strictly specified by the appropriate technical standards related to the safety of flight.

Undertaking the biomechanical subject of study concerning causes and consequences of internal and external forces affecting the man allows to identify exactly helicopter's survivability in the aspect of the biomechanical characteristics of pilot (crew).

Biomechanics as the interdisciplinary scientific area possesses the field of research on the verge of technical and biological sciences (figure 3).

Fig. 3 Biomechanics as the interdisciplinary scientific area

Using the theory of information we can assess PR (Pilot-Crew Rating) after the scale of Cooper-Harper in function of their workload WL. Pilot-Crew workload WL is defined as the quotient of the required informative pilot-crew capacity R regarding disposing (border possibility) informative capacity which pilot-crew C possesses.

So it can be observed that the pilot-crew evaluation amounts to $PR=10$, the value of their workload is: $WL=R/C=1$. This is the necessary condition to achieve the pilot-crew border possibilities. However if the pilot-crew evaluation amounts to $PR=1$, the value of their workload is: $WL=R/C=0$ as the critical value which might be not enough to perform safe air task [14].

Presented assumptions allow to set the equation:

$$PR = 1 + 9 WL \quad (9)$$

where:

$$1 < PR < 10$$

$$0 < WL < 1$$

Taking into account the linear relation between pilot-crew workload WL and handling qualities of helicopter HQ, the equation is in the following form:

$$HQ = 1 - WL \text{ or } WL = 1 - HQ \quad (10)$$

where:

$$0 < HQ < 1$$

Interpreting the formula (10) we should notice that if the handling qualities of helicopter are close to the value $HQ=1$ (perfect maneuverability, liveliness, durability, etc.), the pilot-crew workloads during the flight are slight $WL=0$.

Using the formulas (9) and (10) the correlation between pilot-crew workload and the handling qualities of helicopter can be described by the following equation:

$$PR = 10 - 9HQ \quad \text{or} \quad HQ = 10/9 - PR/9 \quad (11)$$

The analysis of the equation (10) and (11) allows to define the relation between the pilot-crew workload, their skills assessment and the handling qualities of helicopter.

If the pilot-crew workload during the flight performance is close to $WL=1$ and their skills assessment is close to $PR=10$, it can show the bad handling qualities of helicopter, this means the value is close to $HQ=0$.

There is the fact confirmed by the scientific researches which says that during helicopter's control in extreme conditions pilot-crew informative capacity is equal to disposing (border possibility) informative capacity, so $R=C$ with reliability 0.98 [3].

When the informative capacity is lower than disposing informative capacity which pilot-crew possesses, $R < C$ correlated with the appropriate level of helicopter's liveliness, then there is a possibility to increase disposing time t_D to correct mistakes.

This correlation allows to decrease the danger of damage or air-crash.
 This hypothesis can be given in the following form:

$$P_K = P_E P_Z \quad (12)$$

where:

P_K – probability of air-crash;

P_E – probability of pilot and crew mistake;

P_Z – probability of the situation in which paralyzed system won't turn into usable condition causing the possibility of air-crash.

Relation (12) can be written like this:

$$P_K = p^{C/R} P_Z \quad (13)$$

Taking into account the formula (8) and (9), where $WL = C/R$ in the function of evaluation PR we have:

$$P_K = p^{9/(PR-1)} \left(1 - \frac{n}{n + t_Z}\right) \quad (14)$$

The above fact is correlated with the helicopter's survivability and the level of pilot-crew skills, what has the influence on decisions made during helicopter flight performance.

Well trained pilot (crew) who is also in a good physical and mental condition ($PR=10$) supported by the appropriate helicopter's resistance to damages ($HQ=1$), shows the high level of reliability during the dangerous incident during the flight.

Assumptions:

p - probability of making a mistake in conditions $R=C$, so $p=1-0,98=0,02$;

$PR = 3,5$ - average pilot-crew evaluation in phase of approach as one of the most difficult elements during the flight (according to the scale of Cooper-Harper);

$P_Z = 4,6 \cdot 10^{-1}$ - average value of the probability of the situation in which paralyzed system won't turn into usable condition causing the possibility of air-crash (table 2).

Then the probability of air-crash (P_K) amounts to:

$$P_K = 0,02^{9/(3,5-1)} \left(1 - \frac{n}{n+t_Z}\right) = (7,7 \cdot 10^{-7}) \cdot (4,6 \cdot 10^{-1}) = 3,5 \cdot 10^{-7} \quad (15)$$

Received result $3,5 \cdot 10^{-7}$ including the assumed handling qualities of helicopter (resistance to damages – survivability) towards pilot and crew workload in the process of making decisions should be interpreted that there will be 4 air accidents on 10 million landings.

The fixed correlation between the probability (P_Z) of losing flying attributes by the helicopter and the probability (P_E) of pilot and staff mistake taking into account their assessment (PR) in making very hard pilot manoeuvre (the phase of approach) allows to calculate the area of the reduced probability of air-crash (figure 4).

Fig. 4 The area of the reduced probability of air-crash

Including the helicopter's survivability in the aspect of the biomechanical characteristics of pilot and crew might be one of the alternatives to explain the course of events which caused the air accident. This allows to analyse the chain of cause and effect, mutual conditions and interactions between the damages and the decision process of the pilot and the crew.

4. Conclusion

- Contemporary development of biomechanics as the interdisciplinary sphere of technical and medical science allows to create systemic approach where survivability of helicopter is directed toward the preparation of the decision loop of pilot and staff.
- The proper level of helicopter's resistance to damages assures the appropriate time (t_D) to make right decision what has the influence on the safety of flight.
- The fixed correlation between the probability (P_Z) of loosing flying attributes by the helicopter and the probability (P_E) of pilot and staff mistake taking into account their assessment (PR) in making very hard pilot manoeuvre allows to calculate the area of the reduced probability (P_K) of air-crash.
- The fixed area including the biomechanical characteristics of pilot and crew together with the technical characteristics defines the field in which we have to move during the helicopter's project execution just for its safe operation.

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