The change in the probability of aviation accidents “Collision of an aircraft with a bird” in accordance with a change in the temperature cycle

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Abstract. This paper considers the possibility of predicting the most frequent aviation event “Collision of an aircraft with a bird”, depending on the seasonality near the airfield. A model for determining the probability of this event is proposed, where the “time of year” is identified by the predicted air temperature near the airfield in question and the problem of determining the accumulated probability is solved. We consider the first approximation in which events are assumed to be independent (these are complex ecological and ornithological conditions and flaws of airfield’s ornithological support). Due to the first approximation of independence, the paper provides a possible way to determine the probability of the event “Collision of an aircraft with a bird”. This method (in the form of a formula) determines the probability of intersection of events caused by hazard factors. The result of the simulation is the probability of long-term forecasting of the probability of an aviation incident due to an aircraft collision.

1. Introduction
In the present paper the capability of the forecasting of the most frequent aviation incident “Collision of an aircraft with a bird” in dependence on the season near an airfield is considered. The model of determination of the probability of such an event is proposed, where “season” is identified according to the forecast air temperature near the examined airfield. On the basis of this model the calculation of the accumulated possibility of the aviation incident “Collision of an aircraft with a bird” is suggested.

We consider the first approximation in which the events are suggested independent (these are difficult ecological and ornithological conditions and flaws of airfield’s ornithological support). Due to the first approximant a possible method of determination (formula) of the probability of the aviation accident “Collision of an aircraft with a bird” is suggested in the paper. The given formula determines the probability of intersection of events caused by the hazard factors.

The modeling result is the capability of the long-term forecasting of a probability of an aviation incident because of collision of an aircraft with a bird.

The paper consists of performing several interrelated stages:
1). the aviation incident “Collision of an aircraft with a bird” forecasting model development;
2). temperature changing model development;
3). development of model long-term forecasting the likelihood of an aviation incident “Collision of an aircraft with a bird” based to model of temperature changing;
4). determination of accumulated probability of the aviation accident “Collision of an aircraft with a bird”.

At the moment there are a lot of developments that have to apply in aviation incidents forecasting, e.g. [1, 2].

The paper is based on results are given in [3]. The research incident forecasting in the long term perspective is of the greatest interest. Let us consider of each stage more attentively.

In the work [4] authors review statistics of Bird strikes between 1960 and 2014, and Bird strikes present a summary of the damage imposed on the aviation industries by their avian counterparts, offer various methods for minimizing the overall probability of bird-strike events.

In the work [5] ten years of meteorological data collected from six U.S. major airports were used and the results indicated that temperature and precipitation were major factors that have significant effects on bird strike occurrence at most of these airports, while other factors including wind speed, visibility, and pressure, only have effects at certain airports. The study of bird strike severity evaluated the effects of a set of variables, such as airplane mass, engine type, number of engines, altitude, bird size, and strike position of an airplane. The multinomial regression model was used to quantitatively analyze the impacts that such variables pose on three severity categories: no damage, minor damage and serious damage.

2. The aviation incident “Collision of an aircraft with a bird” forecasting model

According to the aviation incidents statistics the basic research factors are “ornithological situation” and “flaws of airfield’s ornithological support”. These two indicators of the airfield are considered hazard factors during the aviation incident “Collision of an aircraft with a bird” forecasting.

The ornithological conditions complexity is determined by the setting and airfield geographical location feature. Further they are called clarifying characteristics of hazard factors. In the given paper it is proposed to evaluate each of these airfield clarifying characteristics by the most significant indicators:

- ecological and ornithological situation - mass morning bird flights, mass evening bird flights, autumn bird migration routes, spring bird migration routes;
- the airfield geographical location feature – water basins availability (rivers, seas, swamps, lakes), fields, availability of grain crops, cattle farms, dumps, grain transportation routes, elevators.

In the paper these two specifying characteristics are suggested as independent because for example the water basin availability assumes increasing a number of birds during numerous flights.

The ornithological situation is the determinant in the bird forecast for the airfield and runway territory.

In the paper, the airfield support is divided into two significant indicators: updated and outdated. At present, to the fist type, we can relate audio telescopes, bioacoustic installations, ultrasonic installations, laser installations. To the second type of equipment - mechanical bird repellents, guns, rattles, rocket launchers, etc. According to the availability or absence of such equipment the hazard factor “flaws of airfield’s ornithological support” is evaluated.

During the research of statistics of aviation incidents collision of an aircraft with bird the interconnection between complex ornithological situation and flaws of airfield’s ornithological support was distinguished and allowed to build the model and determine forecasting method the Collision of an aircraft with a bird.

Let us introduce the mathematical model allowing to create the methodology for determining the aviation incident “Collision of an aircraft with a bird” factor.

Let us consider the probability space \((\Omega, F, P)\). The space of elementary outcomes \(\Omega\) represents a set of the all possible scenario of event development, analyzed in the model. The probability of an incident (hazard factor “flaws of airfield’s ornithological support”) \(B_1\) and an incident (hazard factor “complex ornithological situation”) \(B_2\) is evaluated.
Let us evaluate the probability $P$ of the event $B^1$, which is caused by a number of significant in this research indicators. At present research they are the absence or lack of knowledge about the availability of the above mentioned airfield ornithological equipment.

The assessment of the event $B^1$ is determined as

$$P(B^1) = \min \left\{ \alpha_{11} I(\varphi_{11}^i > 0) + I(\varphi_{11}^i = 0), \alpha_{12} I(\varphi_{12}^i > 0) + I(\varphi_{12}^i = 0) \right\},$$

(1)

where $I(\cdot)$ indicator function, $\alpha_{ij}$ - the significance coefficient demonstrates the probability of function failure of $j$- equipment. Vector $\varphi_{1i}^i$ is determined by expert assessments (people aware with airfield ecological and ornithological situation can be experts), more details given to [3].

The probability $P$ of the incident $B^2$ is determined as the probability of the nonoverlapping events: ecological and ornithological situation ($B^{21}$ in the model), airfield geographical location feature ($B^{22}$ in the model).

$$P(B^2) = P(B^{21} + B^{22}) = P(B^{21}) + P(B^{22}) - P(B^{21}) \cdot P(B^{22})$$

(2)

The given estimation in reality lies in the interval from 0 to 1 (according to Helder’s inequality) [3, 6]. Coefficients $\gamma$ and $\lambda$ are chosen according to the hazard factors values. For these coefficients expressions are executed: $\gamma + \lambda = 1$. $\lambda \in [0,1]$. $\gamma \in [0,1]$. At the present moment $\gamma = \lambda = 1/2$.

Function $I_l$ is an indicator function and equals to 1 if the forecasting time equals the source, for example: the forecasting time is spring, the source indicator spring bird migration will equal to 1.

The probability of the occurrence of aviation event “Collision of an aircraft with a bird” $B$, according to the values found $B^1, B^2$, is defined by the formula:

$$P(B) = P(B^2)(P(B^1))^{1/A}.$$  

(4)

The expression (4) represents the probability of the intersecting of the event $B^1 \cap B^2$ in the first approximation of independence. The selection of parameter $A$ is performed by searching in the range 0.1-10 in increments of 0.1 during trial operation in order to maximize the compliance of the forecast $P(B)$ with a posteriori data.

3. The model “Temperature change”

Let us consider the mathematical model “Temperature change”. It is supposed, that the process of temperature values $X = (X_t)_{t \geq 0}$ is an observed one. At the same time season temperature changes are supposed with some (estimated but initially not measured so consequently unobserved) velocity $Y = (Y_t)_{t \geq 0}$:

$$\begin{cases}
    dX_t = Y_t dt + dU_t \\
    dY_t = -\lambda(X_t - X_{mid}) dt
\end{cases}$$

(with initial values $X_0$ and estimated $Y_0$). Here the variable $\lambda$ determines cyclic changes of season periods and is found (in the first linear approximation) from
the ratio: $\lambda = \omega^2$, $T = \frac{2\pi}{\omega}$ (where $T$ is the cycle length). The average temperature value of a year is defined by the variable $X_{mid}$.

The process $U = (U_i)_{i=0}^\infty$ determines volatility of temperature values and (in the first linear approximation) is the Ornstein-Uhlenbeck process (i.e. stationary Gaussian noise with exponentially attenuated correlation function): $dU_t = -\mu U_t dt + \sigma dW_t$ ($U_0 = 0$) and variance $\mathbb{D}_U(t) = \mathbb{D}_U \cdot (1 - e^{-2\mu t}) = \frac{\sigma^2}{2\mu} (1 - e^{-2\mu t})$. The variance estimate is the experimentally determined (due to the ergodicity of the Ornstein-Uhlenbeck process) value of the quadratic deviation obtained by the formula: $\mathbb{D} = \frac{1}{T} \sum_{t=1}^{[TN]} (\bar{X}_{t_i} - x_i)^2 \Delta$ (where $x_i$ is experimental values for the period under review, $\Delta = \frac{1}{N}$ and $N$ are discreteness of splitting with $t_{i+1} - t_i = \Delta$). The process $\bar{X} = (\bar{X}_{i})_{i=0}^\infty$ is a sinusoid and is described by the system: \[
\begin{aligned}
d\bar{X}_t &= \bar{Y}_t dt \\
d\bar{Y}_t &= -\lambda (\bar{X}_t - X_{mid}) dt
\end{aligned}
\]
(\bar{Y}_0 = Y_0).

Let us consider a discrete analogue of the considered mathematical model. At the first stage, the continuous area is replaced $0 \leq t \leq T$ with a discrete area-a collection of a finite number of points $N \in \mathbb{N}$, $T \in \mathbb{R}^+$. Let us consider a collection of points $\{t_k : t_k = k/N, k = 0, 1, \ldots, [N \cdot T]\}$ (where $[N \cdot T]$ is an integer part of a number $N \cdot T$). Then such a set is a uniform difference grid with a sampling step $\Delta = 1/N$. At the second stage of the transition from a continuous model to a discrete one, discrete analogues of differential equations are constructed (with the corresponding finite differences replacing the differential). Thus, all discrete analogues of the constructed processes are simulated for each of them ($0 \leq k \leq [NT]$): \[
\bar{U}_{k+1} = \bar{U}_k - \mu \bar{U}_k \Delta + \sigma \varepsilon_k
\]
(values $\bar{X}_0 = X_0$, $\bar{Y}_0 = Y_0$, $\bar{U}_0 = U_0$, $\bar{X}_0 = X_0$, $\bar{Y}_0 = Y_0$, $\varepsilon_k$ is a sequence of independent Gaussian random variables with zero mean and variance $1/N$).

The variable $\sigma$ and $\mu$ they are determined based on the following considerations: $\tau = 1/\mu$, $D = \frac{\sqrt{2D_U \mu}}{\mu} = \sqrt{2D \mu}$. Within the discrete model description “Temperature changes” and by virtue of the diffusion approximation theorem [9], weak convergence is performed \[
(X_{NT}, X_{NT}) \rightarrow (\bar{X}_{NT}, \bar{Y}_{NT}, \bar{U}_{NT})_{0 \leq t \leq T}
\]
with $N \rightarrow \infty$. The adaptation is performed when comparing model and experimental posteriori data. The choice of discreteness and the volume of simulated implementations were carried out to ensure the level of difference between discrete and continuous models no higher than 0.05, i.e. $\frac{1}{L} \sum_{i=1}^{L} |\bar{X}_{NT} - x_i| \leq 0.05$. The discretization increases until the changes in the final characteristics are within the preset confidence interval [10], the value $N = 10000$. 


The value of the discrepancy is determined by $\varepsilon = |A - \max_{0 \leq k \leq [NT]} |\tilde{X}_k - X_{mid}| \leq 0.01$ (where $A$ is a value of the model curve amplitude, $0 \leq k \leq [NT]$).

The value of the model parameters “Temperature changing” with the time change insignificantly. As for example, there are statistics of the maximum air temperature values for the last 10 years with the time it is obvious that after three months with these parameters recalculation the difference will occur minimum, [11]. That is why it is preferable to recalculate these parameters in a quite long period of time.

4. Long-term forecasting model of an aviation incident “Collision of an aircraft with a bird”

The classical scheme defines a probabilistic model $(\Omega, F, P)$ and in the case of studying the dynamics of events in time (and the corresponding random processes), a stochastic basis is described $(\Omega, F = (F_\omega)^{\omega \in \Omega}, P)$, where $\Omega$ is the space of elementary events $\omega$, $F$ is $\sigma$-algebra generated by subsets $\Omega$, $F$ is non-decreasing flow of $\sigma$-algebra $F_\omega$, $P$ is probability measure on $F$. In this case, the occurrence of the aviation event in question occurs at a random moment in time $\tau = \tau(\omega) \geq 0$ which is a random variable, and with respect to the stochastic basis-the moment of stopping (in case of $P$ is a final stop time). Let the process $\pi_\omega(t)$ be the conditional instantaneous probability of an incident occurring after the current time $s$ in the time interval from $t$ to $t + \Delta$ on condition of observation till the moment $s$ with $\Delta > 0$ and defined according to the formula (4).

Figure 1 shows the change in the accumulated probability of the occurrence of the aviation event considered here. Each airline, knowing the damage that this aviation event causes, can choose corrective actions, and this probability must be taken into account when making a forecast of other aviation events related, for example, to machinery or human factors. This approach will allow the airline to calculate material damage taking into account the risk and calculate the cost of the flight taking into account this risk.
Figure 1. Graph of the accumulated probability of an aviation incident caused by a collision with a bird.

5. Conclusion
The forecast based on the model of long-term forecasting of the aviation incident “Collision of an aircraft with a bird” allows predicting with a set critical probability the date of occurrence of the considered aviation event. In [12], the relationship of changes in air temperature and time of the collision with a bird is given. In this paper, we take into account the relationship not only of the temperature value but also the data of migration paths, airfield geographical location features, flaws of airfield’s ornithological support. The model was adapted for some airports, and parameters were set automatically. Using this work will reduce the likelihood of incidents involving an aircraft collision with a bird.

6. References
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