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DETERMINATION OF FLIGHT SAFETY RATES AND EXAMINATION OF THEIR VARIATIONS WITH TIME IN CORRELATION TO RELIABILITY RATES

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Introduction

The problem of defining and formulating the rates of flight safety and reliability for aircraft (i.e. airplanes and helicopters) is in practice, and quite often, governed by criteria of effectiveness. While solving this problem, economic issues are taken into consideration. The essential idea is to look for optimum solutions, the most advantageous ones that take account of the following factors: safety, reliability, life, availability, and cost of implementation, i.e. of manufacturing and operating the aircraft.

Examination of the level (state) of flight safety and reliability of aeronautical systems has to be carried out in the course of long-term periods, with changes in both the system's environment and the intensity of operating it taken into account.

Essential considerations included into this paper refer to the air force mainly. Notifiable air accidents, i.e. fatalities (crashes) and failures have been used to illustrate our considerations.

Rates of flight safety

The process of considering the problem of safety has been divided into the following stages:

1. Observations of prerequisites for undesirable events (damages, failures, fatalities /i.e. air crashes/) and development of suitable data carriers - rates of flight safety and reliability;
2. Analysis of states dangerous to flight safety, and of irregularities in course of operating a system;
3. Examination of the formulated rates and their variations with time, formulation of suitable forecasts as well as evolving preventive-treatment methods; evolving techniques of implementing them into operational practice, of verifying the effectiveness of the methods, and of modifying them to increase flight safety.

The accident rate (WW) is the most common measure of accidents in military aviation. It is reckoned from the ratio of the number of air accidents (WL) to the calendar-year flying hours (N) per 100,000 hrs. By analogy, the rate of notifiable accidents (WWc) can be written down in the following way:

$$\mathbf{WWc} = \frac{\mathbf{Wc \cdot 10^5}}{\mathbf{N}} \quad (1)$$

where: Wc - a number of notifiable accidents (fatalities and failures) per year.

Fig. 1 shows changes in the WWc rate for the Polish Air Force (PAF) [1, 3] in the years 1951-96. In spite of the random nature of distribution of values of this rate one can easily distinguish a five-year period, i.e. 1951-55, in the course of which a considerable improvement in flight safety could be found - the WWc value was reduced twice. Subsequent years show lower and lower dynamics as well as gradient of this improvement.

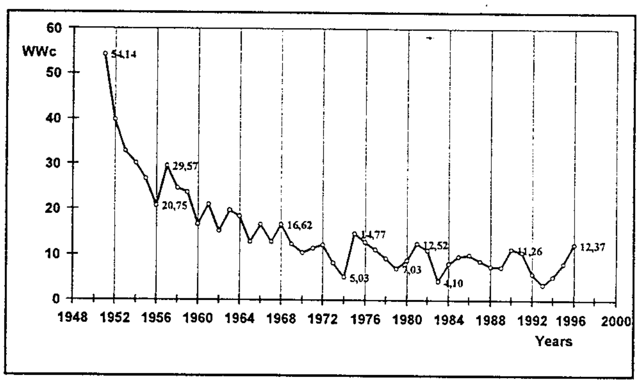

Fig. 1. The rate of notifiable accidents (WWc) in the PAF in the years 1951-96

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Fig. 2 gives a comparison of three countries' rates of notifiable accidents (WWc) for their air forces, i.e. for PAF, USAF, and RAF. What has been clearly shown in this figure are average rates WWc in the past 5-, 10-, and 20-year periods.

The WWc rate is a suitable measure of studying the trend of the characteristic of the system of flight safety throughout many-year period.

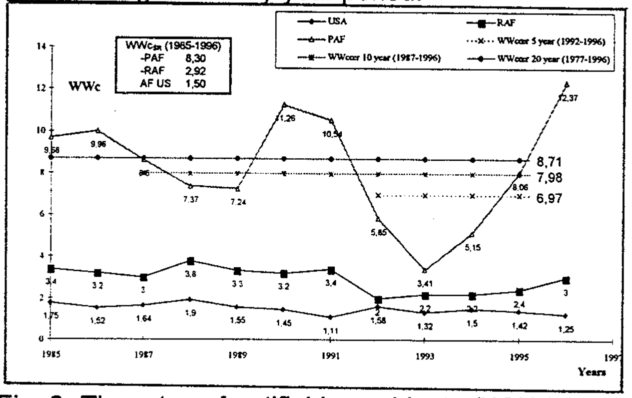

Fig. 2. The rates of notifiable accidents (WWc) in the PAF, USAF and RAF in 1985-96

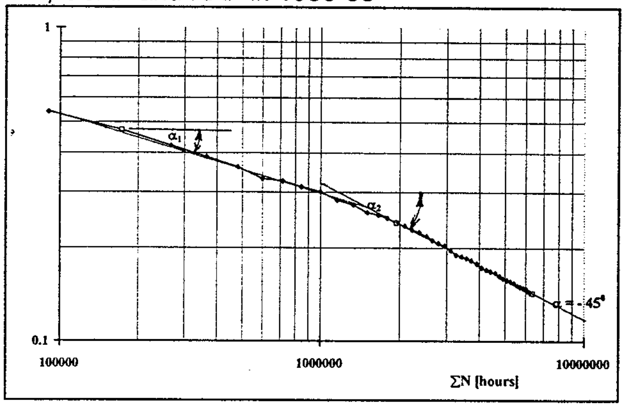

Fig. 3. The change of the Y parameter vs actual sum of total flying time in the PAF in 1951-97

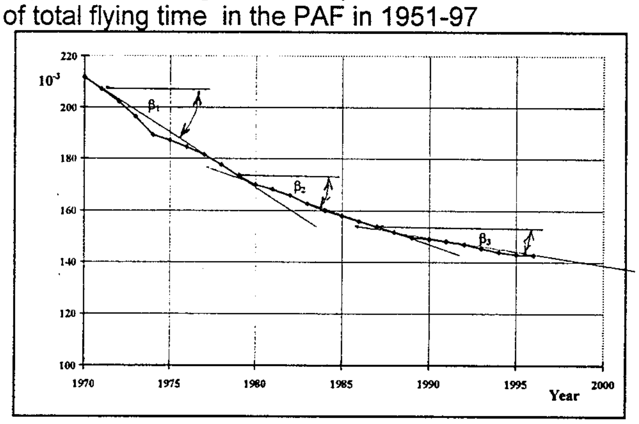

Fig. 4. The change of the Y parameter vs subsequent years (in 1970-97) in the PAF

The following parameter Y has been defined:

$$Y = \sum_{i=1}^{m} Wc_i \Big/ \sum_{i=1}^{m} N_i \qquad (2)$$

where: i = [1, m], m - a variable of the time, e.g. i = 1 corresponds to 1951, etc.

Results of the calculations have been illustrated with Figs 3 and 4. In Fig. 3 that presents $Y=f(\Sigma N_i)$ there are two periods of evident improvement in flight safety. The angle of slope α different from 45^0 indicates t he continuous tendency to losses in aircraft fleet. In Fig. 4 (to linear scale Y and years) one can find, in detail, three periods of improvement in flight safety.

Approximation of the rate of notifiable accidents in the air force

Having assumed the additive model of development of the phenomenon with time, for a given time interval the following equation can be written down to show realizations y_t of the random variable Y:

$$y_t = f(t) + g + z_t \qquad (3)$$

where:

y_t - the observed level of the phenomenon in a given time interval,

f(t) - function of the trend, also called: function of 'transfer', the so-called constant component of the phenomenon,

g - periodical fluctuations resulting from effects of both periodicity and periodical biased factor,

z_t - a residual component, random fluctuations.

Using the Microsoft Excel calculation package (2) computations have been carried out to estimate approximation of the accident rate.

With some data in the form of one-dimensional time series of the accident rates WWc, the trend of changes in this series has been analysed. Time series showing a pretty large share of periodical and random fluctuations are usually subject to sequential treatment to originate a new series showing the development trend of the phenomenon. It results in selecting the causes of steady influence, ones that effect a specific development tendency (3).

The following forms of equations have been arrived at (see Fig. 5); coefficients of coincidence - φ, and curvilinear correlation - ρ have been determined for these forms of equations:

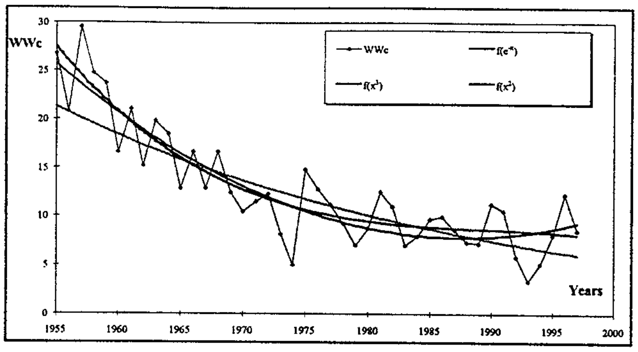

Fig. 5. The regression curve of the rates of notifiable accidents (WWc) in the PAF vs years

A. The exponential form

$$\mathbf{y = 4{,}747 \bullet 10^{27} \bullet e^{-0{,}031x}};$$

$$\varphi = 0{,}5042;\ \rho = 0{,}8636 \quad (4)$$

B. The form of the second-degree curve:

$$\mathbf{y = 0{,}0172x^2 - 68{,}37x + 67943};$$

$$\varphi = 0{,}4490;\ \rho = 0{,}8935 \quad (5)$$

C. The form of the third-degree curve:

$$\mathbf{y = -4{,}48 \bullet 10^{-4} \bullet x^3 + 2{,}67 \bullet x^2 - 5{,}31 \bullet 10^3 \bullet X + 3{,}52 \bullet 10^6};$$

$$\varphi = 0{,}4380;\ \rho = 0{,}8990 \quad (6)$$

Analysis of periodic fluctuations

In order to evaluate periodic fluctuations of the WWc time series obtained due to elimination of the trend of the phenomenon described with the exponential and cubic equations have been analysed. The time series 'cleaned' in this way has been analysed. At the same time an effort has been made to postulate such a periodic curve of the sinusoidal form and constant amplitude, for which the coefficient of coincidence reaches the lowest value. For the needs of calculations the following postulated form of the periodic curve of the characteristic Y - remainders against X - years:

$$\mathbf{Y = d \bullet cos(w \bullet X - q) + b} \quad (7)$$

Apart from the 'short-term' changes in the WWc rate (ones designated with $DWWc^k$) (see Fig. 6) one can find some regularity of the so-called 'long-term' changes. (designated with $DWWc^d$). The long-term changes and their descriptions enable us to draw conclusions on the reasons of such a state (see Fig.7). One of them are a new aeroplanes (see Fig.8)[(4)].

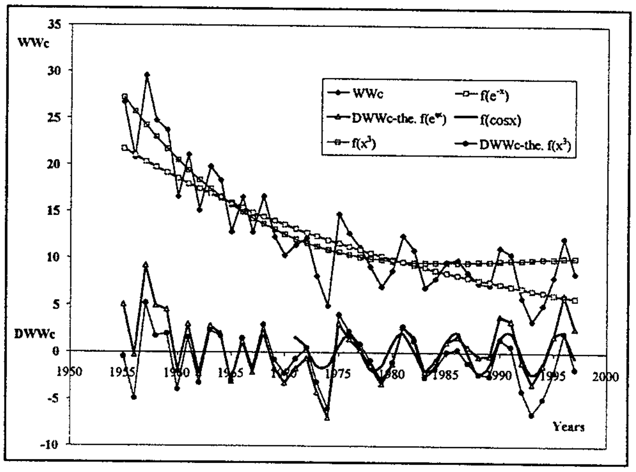

Fig. 6. The empirical curve of the rates of notifiable accidents and its regressions vs years

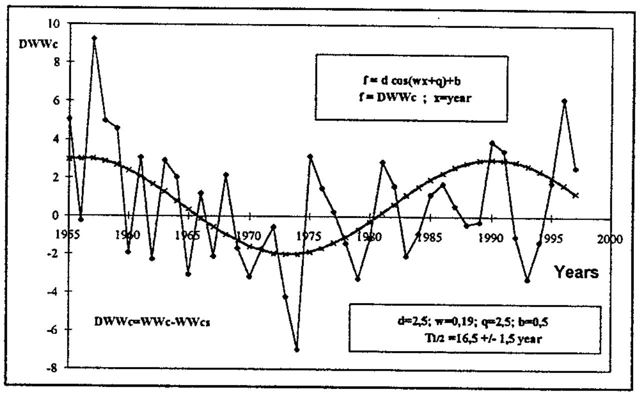

Fig. 7. Smoothing of the characteristic of the long-term component of the WWc rate

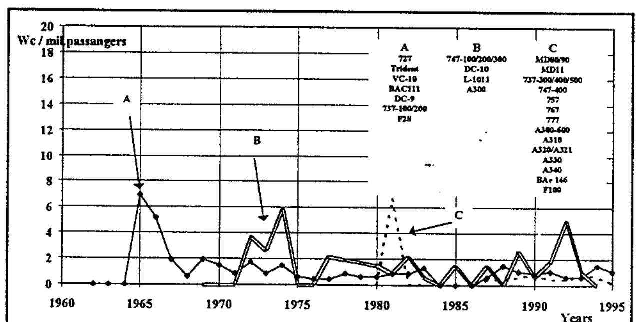

Fig. 8. The accident rates for various generations of civil passenger-carrying aircraft

Table 1 includes estimators of equations of the (2) form. What seems interesting are the observation and calculations of the so-called half-periods of short- and long-term changes $T_{1/2}$, which amount to 2.5 $^+/-$ 0.5 years, and 16.5 $^+/-$ 1.5 years, respectively.

Table 1. Parameters of equations of short- and long-term changes in WWc.

PARAMETER	SHORT-TERM CHANGES $DWWc_{,k}$	LONG-TERM CHANGES $DWWc_{,d}$
d	2.5	2.5
w	1.31	0.19
q	0.25	2.5
b	0	0.5
$T_{1/2}$	2.5	16
$^{+}/_{-}\Delta T_{1/2}$	0.5	1.5

Conclusion

The rates of flight safety formulated in the paper enable investigation into minor and notifiable air accidents (the latter including aircraft failures and crashes). It has been found that the rate of fatal air accidents includes: a constant component, a component of long-term changes, and a component of short-term changes. For all these components the estimated analytical equations have been derived. On the basis of such equations some changes in the flying safety level can be forecasted. Then, searching for correlations with rates of reliability one can determine, which ones show considerable effect upon flight safety and how they should be modified in course of operational practice. In long-term cycles of improvement/deterioration of flight safety some structural changes in airborne systems take place, first of all ones that consist in acquiring new components (mainly aircraft) from the system's environment or in withdrawal of the used-up ones. Similar changes in the accident rate have been observed in general aviation for various generations of passenger-carrying airplanes (see Fig. 8) (4).

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