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RISK ANALYSIS AND THE ELEMENTS OF FLIGHT SECURITY

The problem of risk analysis for civil aviation airplanes is studied. We have investigated independent examples of risk analysis calculations for flight accidents.

Keywords: catastrophe, risk-analysis, expenditures, profit, accident probability.

Safety is an important issue in human activity of any kind. It is most important in the so called traditionally dangerous fields, such as aviation. Technical malfunctions, mistakes made by the crew and ground services – all these factors can be the cause of accidents occurring in aviation. However, the casualties and loses in the civil aviation are still less, than in other dangerous professions and fields of human activity. This relative security is achieved by scrupulous monitoring of this sector and by large expenditures; special attention is paid to the technical conditions of aircraft, and to the work of personal engaged in conducting the flights. The finances spent on the safety maintenance differ in origin, i. e. it is difficult to track all the expenditures. It is necessary to form and solve the problem of correlating the amount of spent monetary resources and the level of security achieved. Work [1] depicts a parabola of profit and expenditure resulting from resources, invested into the aforementioned security (figure 1).

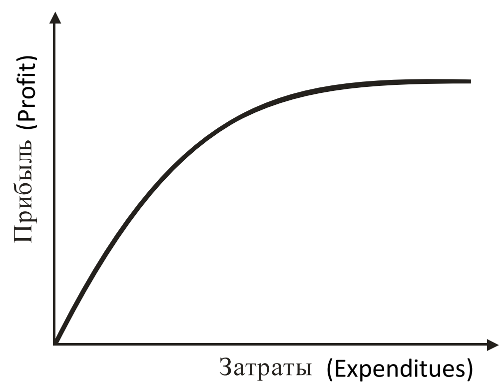

Fig. 1. Expenditure and profit

It would be necessary to notice, that the parabola is the same for all kinds of human activities. The only difference is that of profit and expenditure. It is said, that investments in security are reasonable only to the point, when expenditures are lower than profit. As profit, we see the decrease of loses from aircraft accidents that had been prevented by organized security activities – which of course, were invested into. The criteria of expenditure and profit equality is rather worthy. We do not consider here the aspect of moral.

The feature of the profit-expenditure parabola shows that the efficiency of the expenditures decreases as they increase. This is a good example of the idea that however high the expenses are, absolute security cannot be achieved. There is always the danger of an accident. The features of the parabola can be presented in the following exponential dependence:

$$\Pi_{\text{приб}} = 1 - e^{-(З-З_0)3}, \qquad (1)$$

where З are the security expenditures; $З_0$ – primary (executed before) expenditures.

Dependences constructed with the help of (1) are shown in figure 2. They state that the greater the level of primary expenditures is $З_0$ – the greater the profit from additional expenditures. However, if there is a lower diapason of realized expenditures, the efficiency of them decreases. The primary expenditures level $З_0$ varies by branches and activities.

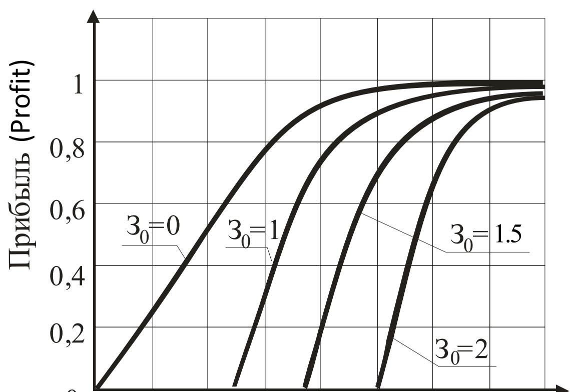

Fig. 2. Dependence of profit from security maintenance expenditures for various primary expenditures

Even though the proposed model (1) joins profit and expenditure, it cannot reveal the mechanism for forming them.

We have made an attempt to do so by investigating the expenditure increase for improving the reliability of aircraft from accidents.

We have studied the statistics of 50 accidents in the Russian Federation that have occurred during the last years with civil airplanes and helicopters. Reasons for 97 % of the accidents are connected to a negative human factor. 3 % resulted due to aircraft malfunctions, caused by flaws in the construction and production. 94 % out of 97 % cases of accidents are due to mistakes made by the crew. The other 3 % are results of low quality aircraft maintenance by ground and supply personal.

3 % of the accidents (from the total sum), resulting because of technical malfunctions are caused by engine breakdowns. We have not recorded accidents caused by errors in the aircraft's functioning systems.

Accidents, caused by malfunctions of the engines should be reviewed separately. The breakdown of an engine on a single-engine aircraft leads to disaster, if conditions for an emergency landing are impossible.

For major airliners with two or more engines, the breakdown of one engine usually does not result in a fatal accident. The time when 4-engine planes were considered to be safer that two-engine (a 4-engine plane can continue its flight with one engine down, while a 2-engine cannot) has long passed.

ICAO regulations state that planes with two engines must be able to sustain themselves in air for at least three hours in case of a breakdown of one engine. This time should be enough to finish the flight or to find a safe landing area.

Malfunctions are more dangerous if they result in fires onboard the plane, or cause destruction to the systems of the aircraft. These factors make it impossible to safely continue the flight. This has changed the concept of reserving engines onboard.

The modern aircraft industry lets us produce aircraft engines of both greater and lower thrust power with relative reliability. This catastrophically increases the possibility of engine breakdowns that will result in tragedy; the more engines a craft carries – the greater the risk. This led to constructing aircraft with two engines, the thrust power of which had been increased; naturally in craft, where two engines were enough.

Engines with greater thrust are much more expensive to produce. The cost of one kilogram of thrust is approximately proportional to the third level of increasing thrust.

These ideas make it possible to construct the parabola for expenditure and profit for the value of flight security, caused by the safety of the engines.

Let's look at the cost formation for the aircraft engines. The cost of one kilogram of thrust is proportional to degree k increasing its thrust n times.

Let's suppose that the basic engine has thrust P_0 and cost $Ц_0$. The plane has m_0 basic engines the thrust if which are:

$$T = P_0 m_0.$$

The cost of the basic engine installation is:

$$C_0 = Ц_0 m_0.$$

If we increase the engines thrust n times, the cost of one kilogram of thrust increases n^k times, increasing the total cost of the engine n^{k+1} times. When the thrust of the engine is fixed T there will be in n times less engines on the aircraft. The cost of the engine installation with fewer engines will be:

$$C_n = C_0 \cdot n^k. \quad (2)$$

To evaluate the losses from accidents let's state a possibility of engine malfunctions equal to10^{-9} for one hour of flight. In reality it is lower, but the standards of flight guarantee [2] dictates a given limit value of accident possibility, caused by aircraft malfunctions is equal to 10^{-9} fo one hour of flight. Let's suppose that loses resulted by one accident are equal to C_k and that the whole basic engine installation contains m_0 engines. Then the possibility of engine breakdown during one flight hour is:

$$Q_0 = 1-(1-10^{-9})^{m_0}.$$

Increasing the engines thrust n times proportionally decreases their quantity in the installation and the breakdown possibility will be:

$$Q_n = 1-(1-10^{-9})^{\frac{m_0}{n}}.$$

Then the possible loses from accidents will be

$$C_{kn} = C_k Q_n = [1-(1-10^{-9})^{\frac{m_0}{n}}]C_k. \quad (3)$$

Expressions (2) and (3) in parametric form define the parabola of security expenditure – the loses from accidents in parameter n. It is expressed in (2) in the form of

$$n = \sqrt[k]{\frac{C_n}{C_0}}.$$

If we will place n in equalization (3) we will eventually have

$$C_{nk} = [1-(1-10^{-9})^{m_0 \sqrt[k]{\frac{C_0}{C_n}}}]C_k. \quad (4)$$

Since C_0 and C_k are unknown to us, the change in expenditure and in loses, it is easier to find their values, using expressions (2) and (3) in shares C_0 and C_{kn}.

The calculation results for cases of price increase of 1 kg of thrust are proportional to the second and third step of engine thrust increase. They are presented in figure 3. We can see that when $k = 2$ and $k = 3$, there is a decrease in efficiency, reducing the amount of accident loses, and an increase of expenditure; this respects to the model of expenditure – profit in [1] when applied to flight security.

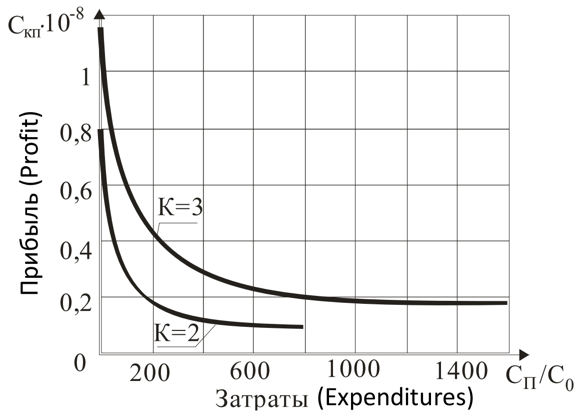

Fig. 3. Dependence of accident loses in the expenditure function

The study of expenditure and profit in cases with a constant number of *m* aircraft engines and the increase in thrust is of great interest. When the engine thrust is increased *n* times, the price of each kilogram of thrust increases by n^k times, the price of the engine n^{k+1} times. The cost of one installation will be:

$$C_n = C_0 n^{k+1}. \quad (5)$$

During this the common thrust of the engine installation increases proportionally *n*. The aircraft's flight mass, passenger capacity, and loses from an accident increase with the thrust, i. e.

$$C_k = C_{n0} \cdot n.$$

In this case (considering the risk) the loses will be:

$$C_{kn} = nC_{k0} \cdot Q_n.$$

Since there are two engines, the final calculated expression will be:

$$C_{kn} = nC_{k0}[1-(1-10^{-9})^2]. \quad (6)$$

The dependence of loses from accidents in the expenditure function from the increase of engine installation thrust is depicted in figure 4. Contrary to figure 3, loses from accidents here increase when the expenditures on engine installations increase. The loses in this case are connected to the increase in passenger capacity of an aircraft, while the reliability of he engines has not changes. With the increase of engine thrust – the price of the engine installation also increases, due to the possibility of accidents.

This can create a false notion that the amount of possible casualties from accidents decreases. In reality such a dependence feature of the engine installation from expenditure and loss, points out that beginning from some value of the expenditure (the engine installation) becomes so intense, that this solution becomes a dead end and no longer works.

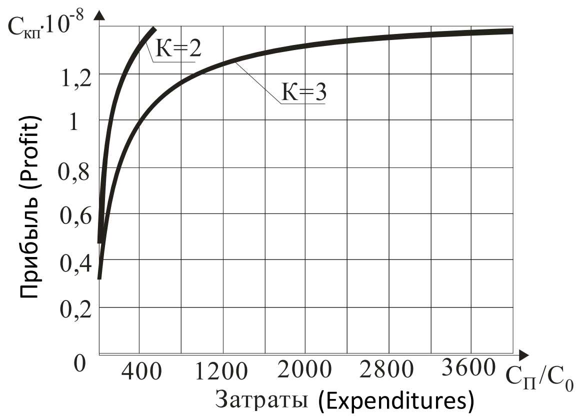

Fig. 4. Dependence of loses in the expenditure function for engine thrust increase

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