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INTELEKTUĀLĀS TRANSPORTA SISTĒMAS

ESTIMATION METHODOLOGY OF AIRCRAFT CREW FUNCTIONAL ACTIVITY

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1. Introduction

The mathematical model of “operator – vehicle – environment" system functioning offered by the authors of the work [1] gives opportunity to determine the criteria of quantitative estimation of aircraft crew training in different situations. A definite kind of model depends on a definite functional task of an operator, or a crew member. The process of aircraft handling includes piloting, operating the systems by crew members as well as decision-making. Let us consider the construction peculiarities of mathematical models for estimating crew functional activity for each of these processes.

2. Quantitative Estimation of Piloting Technique

While training crews on simulators there appears the necessity to estimate their piloting technique. The quantitative piloting technique estimation is carried out by means of valuating the considered parameter divergences from the specified variable. Inconsistency between the standardized and the current values of the control object parameters is regarded as divergence. For the case of crew activity estimation during the flight, the inconsistencies between the standardized and the current values of the parameters, which characterize aircraft’s position and motion in space, are regarded as divergences.

When divergences in piloting are present it is possible to extract two characteristic cases:

1. If the standardized variable is assumed by a definite value (for instance, take-off reference speed or landing speed), the divergence is recorded as a difference (see Fig. 1):

$$\pm \Delta x = x - x_0,$$

where x, x_0 are correspondingly the actual and the standardized values of the analysed parameter.

2. In the case when standardized parameter is situated in some region of acceptable operating values, divergences are represented as a difference between the actual value of the analysed parameter and its standardized minimum and maximum value (see Fig. 2):

$$\Delta x = \begin{cases} x - x_{0\max} & \text{при } x > x_{0\max} \\ x - x_{0\min} & \text{при } x < x_{0\min} \end{cases}$$

where x_{0max}, x_{0min} are acceptable values of the analysed parameter.

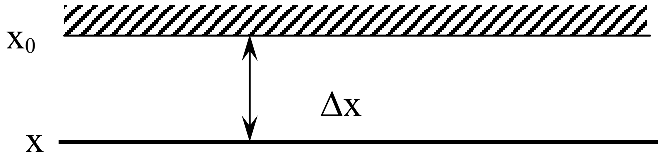

Fig.1. Diagram of one-sided acceptable region of parameter divergence

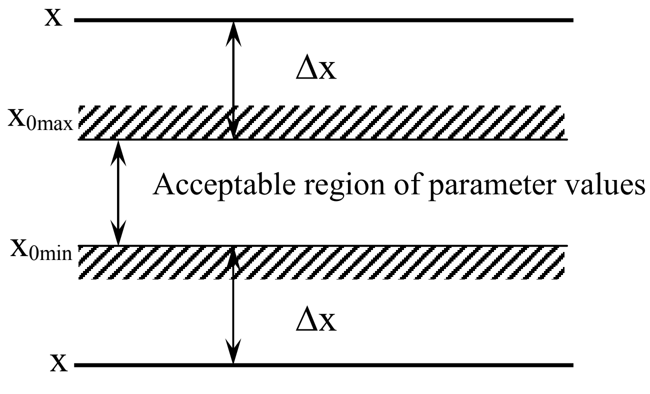

Fig. 2. Diagram of two-sided acceptable region of parameter values

Each divergence of Δx parameter is assigned a corresponding (numerical) score depending on the influence of this divergence upon flight safety. In many cases guideline documents contain the parameter value limit only, corresponding either to the operating or to the rated value without the differentiation of standards inside Δx range. Nevertheless, in the process of crew training, there arises the necessity to carry out a differentiated estimation of parameter divergences in Δx interval.

In a general case, according to five-grade scale, it is possible to extract Δx_1, Δx_2, Δx_3, Δx_4 intervals, and each of them should be assigned a corresponding estimation: “excellent”, “inaccuracy”, “incorrect action”, “error”, or their interpretation in numbers. Differentiation of estimation can also be carried out depending on the consequences caused by each definite divergence (see Fig. 3).

In practice, the unambiguous definition of consequences caused by the divergence, which has been admitted by the crew, requires special experiments or processing of a large volume of statistical data related to the consequences of the divergences admitted during real flights. This procedure is labour-intensive, costly and not always realizable according to flight safety conditions. In the process of training the use of simpler but not less efficient criteria based on statistical approaches is allowed. More detailed application of this approach for the definition of standards for the differentiated estimation of piloting technique is considered in work [2].

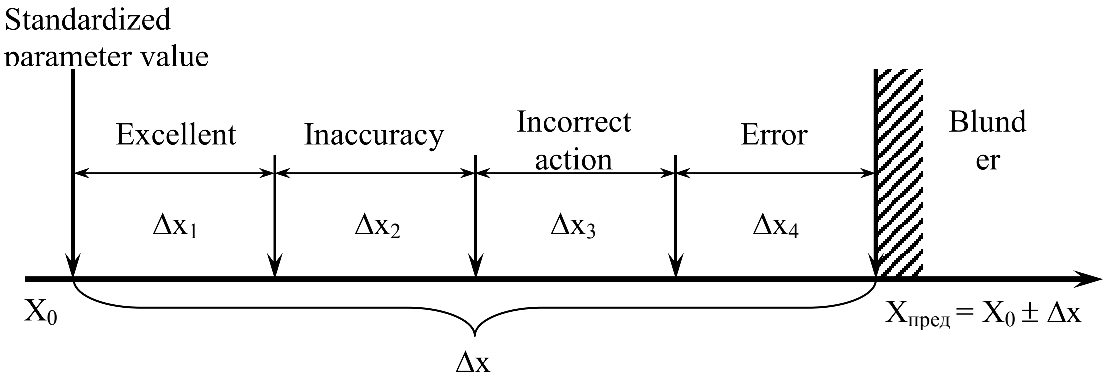

Fig. 3. Differentiated estimation of parameters divergence

3. Estimation Model of Crew Work Technology with Aircraft Systems

Aircraft systems control has a discrete nature, representing a set of consecutive actions. Each discrete action of the crew such as “on” or “off” is considered as an event in a chain of other events. Equipment and plane system operation procedure for each stage of flight in standard situations and in cases of failure and systems malfunctions is stipulated by an aircraft and its systems maintenance guide as well as an aircraft flight guide.

The necessity of starting or finishing the operations for the control of aircraft systems are defined by flight stages, parameter limitations of aircraft position and motion in space as well as time parameters. Operation of systems by the crew which is not stipulated by flight control fundamentals must be regarded as errors. The examples of such actions are the following:

- unnecessary cut-off of properly functioning engine;
- gearing extension at all stages of flight except the one stipulated by guideline documents;
- extension or retraction of flaps at inadmissible speeds and other wrongful actions.

If the expected event had not been performed until the moment the flight parameters reached the value specified in aircraft maintenance regulatory documents, or when there appeared other conditions for the action performance, or the time of event expectation has elapsed (reaction time limit - t_p), non-performance of this action should also be regarded as an error made by the crew. Thus it is necessary to estimate not only the correctness but also the timeliness of crew action when operating aircraft systems.

Estimation of crew action correctness while operating the systems should be considered from the point of view of flight safety. In order to perform any action with the systems, some specified Q_x region is defined:

$$Q_x \subset |x_{au}\ ,\ x_{ap}|\ ,$$

where x_{au}, x_{ap} are the upper and the lower limits (which are defined according to flight safety conditions) of the limitation system for the parameters of aircraft motion, flight stages and time of action performance by the crew when operating the aircraft systems.

By analogy with expression (9) [1] the necessary condition of the crew's accurate work with the aircraft systems can be recorded as follows:

$$x_i \in Q_x \qquad \text{for } \omega_l \in W\ ,\ t \in T.$$

Falling of at least one key parameter of crew action outside the limits of the specified region must be regarded as an error made by the crew. Similarly to the case of analogous parameters, depending on the consequences, the quantitative estimation of crew errors, for example, according to the five-grade scale, is carried out. The estimation of danger degree must be carried out by a group of experts including test pilots, specialists in the field of flight dynamics, systems reliability, and flight safety. Determining the degree of danger of a definite divergence, it is necessary to take into account the results of flight and structural tests, the analysis of reasons and consequences of flight incidents.

A probabilistic approach to estimating the timeliness of crew actions may be applied. The conditional probability of crew's parrying the consequences of system failure during the fixed period of time can be assumed as an index of action timeliness, which means the probability of task fulfilment in the course of time $\tau \leq t_p$ where t_p is a time limit, falling outside which is considered to be an error. For example, having defined t_p and knowing the distribution law of random variable of system failure parrying time t_a, it is possible to determine the probability of timeliness P_{cb} using the following formula:

$$P_{cb} = P(0 < t_a \leq t_p) = \int_0^{t_p} f(t_a)\,dt_a\ , \qquad (1)$$

where $f(t_a)$ is the distribution density of failure parrying time by the crew.

In many cases the value of analogous flight parameter for a definite segment of flight may stand as a parameter characterizing the timeliness of crew actions. Then t_p, t_a and $f(t_a)$ will correspondingly be a parameter limit; a parameter value at which failure parrying has been performed; a distribution density of failure parrying parameter values. In this case the approach to the estimation of crew action timeliness will be the same as in the case when the time of action is a criterion of timeliness.

t_p value can be both the constant and the random variable. In the first case t_p is specified by aircraft maintenance regulatory documents. The assignment of t_p limit value as well as determining the consequences of non-performance of actions up to this value turn out to be a complicated task because it is necessary to take into consideration a majority of different factors. In regulatory documents there are usually specified the segments of flight and the values of analogous parameters at the beginning of a definite action performance directed to aircraft systems operation. Time indices are specified much more rarely. As an example of flight segments appropriation and parameter values at the beginning of actions with the systems, there may be drawn the following requirements: in case of engine failure according to "chip in oil” criterion while taking-off, it is necessary to cut-off the engine at the circle height. As a rule, in flight control fundamentals there are no definite directions in respect of t_p time.

In cases when it is impossible to define t_p value on the basis of aircraft system functioning analysis, results of flight tests and other data, it should be defined on the basis of flight data statistical processing. Having an array of the given values of time or failure parrying flight parameters, it is necessary to define the distribution law of random variable; then, having assigned a necessary probability level of failure parrying timeliness, it is necessary to determine t_p value.

It is possible to apply the same approach for the differentiated estimation of operation timeliness as in the case of quantitative estimation of piloting technique. So it is necessary to determine the limit value of flight parameter or t_p time, before which it is necessary to turn the system on/off. For separate systems there exists a range of acceptable time values from t_{pmin} to t_{pmax}, in course of which it is required to perform the necessary action with the system. In this case the formula of failure parrying timeliness probability (1) changes in a following way:

$$P_{cb} = P(t_{pmin} \leq t_a \leq t_{pmax}) = \int_{t_{pmin}}^{t_{pmax}} f(t_a)\,dt_a \ , \qquad (2)$$

Non-performance of the required action when operating the system by the crew up to t_{pmax} limit time value as well as earlier performance of t_{pmin} must be estimated using a corresponding score depending on the consequences which may be entailed by such a divergence from limitations. For instance, laboratory research of fire-extinguishing systems for “Tu-154” planes showed that in case of not taking any fire fighting measures during 60 seconds from the moment of fire commencement the subsequent fire extinguishing is nearly impossible. In this case the crew’s delay in operating the fire-extinguishing system, which exceeds t_p, must be regarded as a “blunder”. A graphic illustration of such situation is represented in Fig. 4.

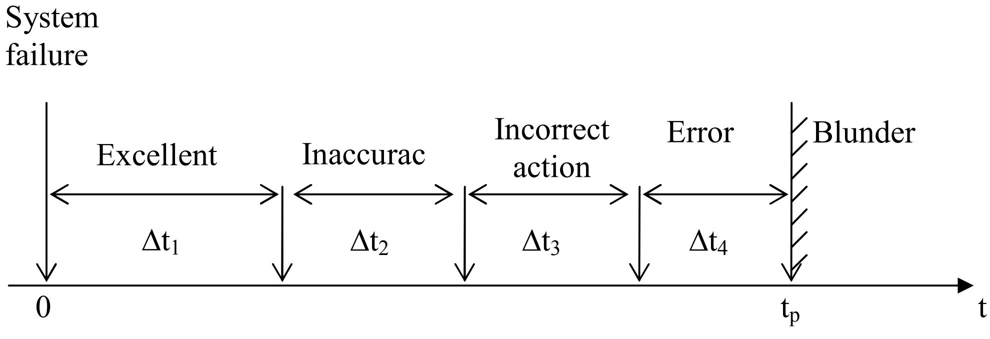

Fig. 4. Estimation of crew action timeliness when operating aircraft systems

If necessary, the actions of the crew when operating the systems in the interval from 0 to t_p can also be estimated differentially. In a general case, using the five-grade scale, it is possible to extract Δt_1, Δt_2, Δt_3, Δt_4 time intervals; each of them must be correspondingly estimated by "excellent", "inaccuracy", "incorrect action", "error", or their interpretation in numbers. Differentiation of estimates is also carried out depending on the consequences to which the delay in action performance may lead.

4. Estimation Model of Decision-making by Aircraft Crew

Estimating the functional efficiency of the crew, the question of correctness of decisions made by the crew should be considered separately. The process of decision-making represents the combination of operator's complex analytical activity including information acceptance and analysis, current situation assessment, elaborating the decision for further actions and the actions concerning practical realization of the decision. The practical realization of the decision represents the combination of piloting technique and work technology – their estimation methodology has been described above. As regards the analytical activity of the crew directed at decision-making, there exist theoretical models of operator’s psychophysiological activity, but at present the practical realization of such models is embarrassed. Therefore in the accepted model of “crew – aircraft” ergatic system (ES) it is expedient to estimate the final result and not the process of decision-making itself.

The flight control fundamentals contain the parameters of aircraft motion, aircraft systems condition, and ambient conditions for each stage of flight, which guarantee the safe continuation of flight according to the designed scenario. Thus there exists some Q_x region defining the flight safety at each stage:

$$Q_x \subset |x_{au}, x_{ap}|,$$

where x_{au}, x_{ap} are the upper and lower limits (which are defined according to flight safety conditions) of the limitation system for aircraft motion parameters, flight stages and ambient conditions.

Then the necessary condition of s_e aim achievement, or the continuation of flight according to the designed scenario, can be recorded as follows:

$$x_e \in Q_x \qquad \text{для } \omega \in W_e, t \in T_e, \tag{3}$$

where T_e is the time of definite flight segment; W_e are ambient conditions determining the safe passing of the assigned flight segment.

The pilot in “crew – aircraft” ES structure forms h_e, or control actions, for the given limitations, which ensure the achievement of s_e control aim for the given segment of flight:

$$h_e \rightarrow [x(t_e) \in s_e], \ \omega \in W_e.$$

Falling of at least one key parameters outside the limits of the specified limitation region (3) ($x_{ea} \notin Q_x$) must be regarded as the necessity of setting a new piloting aim (s_{ea}) by the crew, which means the alteration of flight profile. To achieve the new aim the crew forms h_{ea}, or a control action with the consideration of the existing x_{ea} situation:

$$h_{ea} \notin h_e.$$

As a result of fulfilment of h_{ea} algorithm, or actions, by the pilot, aircraft is transferred from the initial state $x = x(t_e)$ to a new state $x = x(t_{ea})$ corresponding to the alteration of flight profile.

If the pilot's formed algorithms of actions refer to class h_e, which do not correspond to the existing x_{ea} situation, their realization at the given stage of the flight will be regarded as a decision-making error made by the crew. Another example of decision-making error is the situation when the crew has passed to new control actions h_{ea} while the former situation still exists, which corresponds to expression (3). Depending on the seriousness of possible consequences the crew's wrong decision-making will be estimated differentially.

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Viktors Feofanovs, Aleksandrs Urbahs. Gaisa kuģu apkalpes locekļu funkcionālas darbības novērtēšanas metodoloģija

Sistēmas „operators – transporta līdzeklis – apkārtējā vide" funkcionēšanas matemātiskā modeļa pamatā autori piedāvā gaisa kuģu apkalpes locekļu sagatavotības novērtējuma kritēriju metodoloģiju dažādās situācijās. Tika piedāvāts noteikts novērtēšanas modelis atkarībā no operatora – apkalpes locekļa funkcionāliem uzdevumiem. Tika apskatīta apkalpes locekļu darbību novērtēšanas metodoloģija pilotējot gaisa kuģi, strādājot ar tā sistēmām, kā arī pieņemot lēmumus.

Viktor Feofanov, Alexander Urbach. Estimation methodology of aircraft crew functional activity

On the basis of the mathematical model of "operator – vehicle – ambient conditions" system functioning the authors offer the methodology of criterion estimation of aircraft crew training in different situations. There are offered some definite estimation models depending on the functional tasks of the operator, or the crew member. There is also considered the methodology for estimating the actions of the crew during aircraft piloting, systems operating, and decision-making.

Виктор Феофанов, Александр Урбах. Методология оценивания функциональной деятельности экипажей воздушных судов

На основе математической модели функционирования системы «оператор – транспортное средство – окружающая среда» авторами предложена методология критериальной оценки подготовленности экипажей воздушных судов в различных ситуациях. Предложена конкретные модели оценивания в зависимости от функциональных задач оператора – члена экипажа. Рассмотрена методология оценивания действий экипажа при пилотировании воздушного судна, при его работе с системами, а также при принятии решений.