Differential Evaluation of Crew Functional Effectiveness

Viktors Feofanovs

Institute of Aeronautics, Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, Riga, Latvia

Abstract – **The aim of this article is the development of the system and methodology of complex control and evaluation of vehicle operators performance during multifunctional simulation. In order to achieve the above-stated aim it is necessary to solve the following principal tasks: to elaborate a theoretical model of differentiated evaluation of vehicle operator training degree according to different kinds of their functional performance; to develop the method of the differential evaluation of crew performance on full-scale aviation simulators with due consideration of the probabilistic approach on the basis of statistical processing of the data of recorded flight information. The offered theoretical model of the differential evaluation of operator performance and the methodology of standards determination developed on its basis represent a new approach to the creation of automated systems for the objective evaluation of the trainees' qualification degree. The elaborated system of differential evaluation standards ensures a high degree of objectiveness when evaluating the degree of the vehicle operator qualification and makes it possible to carry out a comparative analysis of the operators' qualification.**

Keywords – **Flight simulators, control and evaluation of the crew's actions, crew's functional efficiency, transport system.**

I. INTRODUCTION

Wide application of high-performance multifunctional simulators in the process of transport vehicle operator training required the development of new approaches to the training process, as well as the development of high-performance training techniques, because the extension of simulators functionality results in a considerable increase of the load of simulator instructor and as a consequence to his performance impairment. Most often, this leads to the instructor's inability to adequately evaluate the whole flow of incoming information, which considerably decreases the objectivity of the evaluation of the operator's actions. In addition, the basic problem is a criterial evaluation of the degree of vehicle operator professional training with a sufficient degree of confidence [1] – [3].

The problem is that some standards, which are used to evaluate the level of professional training, have clearly vague content and are formulated using the linguistic variables, which do not correspond to clear, quantitative recommendations necessary for machine evaluation [4]. Therefore the evaluation process has mostly a subjective nature, where the instructor of a simulator acts as an expert including all drawbacks inherent in human. One of the ways of solving this problem is the creation of Objective Control and Evaluation Systems (OCES) for evaluating the operators performance in the process of vehicle simulation.

The analysis of the sources of information about the developments in the field of vehicle operator performance control systems showed that by now there are not created any systems capable of performing the differential evaluation of operator's actions. However, from the analysis it follows that the development and application of objective control systems is given much attention all over the world. The most widely spread are the systems increasing the data load on the instructor and helping him to evaluate the qualification of vehicle operators more objectively. At the same time there are no real methods and algorithms of vehicle operator performance evaluation, and very often the necessity

of such systems is just being spoken about especially when training devices without an instructor are used [5], [6].

II. ANALYTICAL MODEL OF THE "CREW–AIRCRAFT" SYSTEM

In general "human–vehicle–environment" systems belong to the class of ergatic systems (ES), and the interaction of their separate elements can be represented as structural diagram contained in Fig. 1 [7] – [9].

In ES structure there circulates the data represented by:
- state vectors of the control object (CO): $X = X_1 ∪ X_2$, where X_1 is the data presented directly to the operator, X_2 is the data entering the channels of automatic control systems;
- position vectors of the control devices (CD) $U = u_1, u_2, …, u_n$;
- vectors of the operator's control actions $h = h_1, h_2, …, h_n$;
- vectors of environmental perturbations ω;
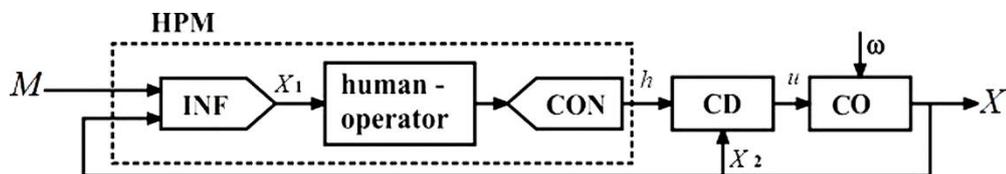- multitude of the objectives of the task being performed $M = m_1, m_2, …, m_n$.

Fig. 1.   Structure of an ergatic system: INF - devices, panel, indicators, etc.;
CON - levers, switches, buttons and other ES control elements;
HPM – integrated element "human – performance means"; CD – control devices; CO – control object.

The algorithm of ES functioning is as follows: by means of INF vehicle operator receives necessary information about the condition of the control object (CO) and then, in accordance with the set objective M, through control devices CD, he changes the condition of the control object in a necessary way using the control actions upon CON for this purpose.

Thus, considering ES structure of different vehicles, it is possible to mark out three basic components: HPM, CD, CO.

In accordance with the diagram of data flow circulation inside the ES, for each of its components it is possible to mark out a circle of variables forming the surfaces, which determine the functioning in time period t of both separate parts and of the system as a whole [10]:

$$
\begin{array}{lll}
\text{for CO} & – & < X, U, \omega, t >; \\
\text{for CD} & – & < x_2, h, U, t >; \\
\text{for HPM} & – & < x_1, h, M, t >.
\end{array}
\qquad (1)
$$

At the same time the regularities and ranges of variable change are restricted by technical data of the vehicles and their systems as well as by operation regulations.

III. DIFFERENTIAL EVALUATION OF CREW FUNCTIONAL EFFECTIVENESS

Functional effectiveness of the crew members is characterized by the ability to see the explicit or implicit features of flight situation complication, forecast its progress, map out the ways of preventing the complication of a situation, make a decision, which is adequate in the given situation, and implement it quickly. Moreover the higher is the functional effectiveness of the pilot, the earlier he will take the necessary measures. In other words, he will need less time to recognize a possible flight situation, which means that he will have more time to prevent it. As a result his preventive actions will prove to be more effective.

Thus the functional effectiveness of the aircraft crew may be represented as its reliability in the "crew–aircraft" system [9].

A. Vehicle Operator Functional Effectiveness Evaluation

In general the functional performance of the aircraft crew should be represented as some integral function joining the functional effectiveness indices of separate crew members. The complexity of the integrated evaluation of the crew functional effectiveness is that the interrelation between separate crew members is not only complex, but also exposed to random actions. The error of some certain crew member is not always the reason of the error made, because a whole chain of wrong actions taken by several crew members may become the reason for the error. All the above-said makes it possible to represent only a general diagram of crew members interrelation (see Fig. 2).
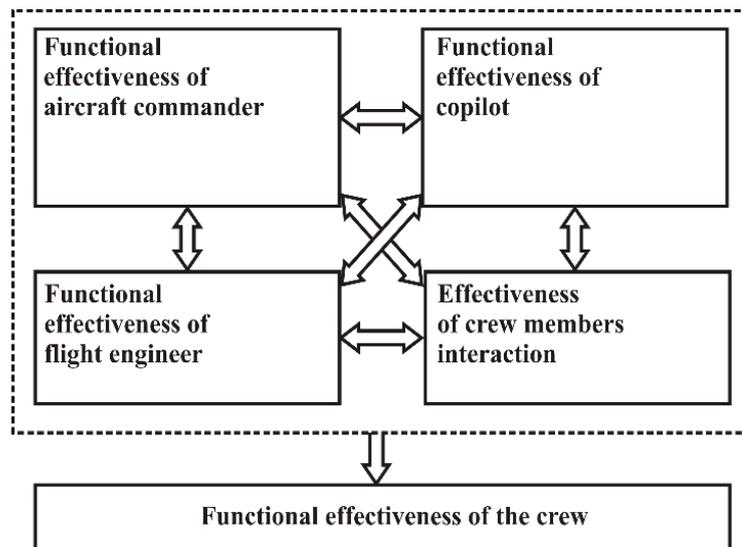

Fig. 2. Diagram of crew functional effectiveness formation.

Evaluating the crew performance during the simulator training it is difficult to take into consideration numerous factors, which influence the functional effectiveness of separate crew members, therefore it is expedient to consider the generalized indices of the whole crew rather than the detailed totality of functional effectiveness of each separate member of the crew. Moreover the generalized indices will characterize the result achieved by the interaction of the whole crew within the "crew–aircraft" system [11].

B. Differential Evaluation of Crew Functional Effectiveness

In accordance with the accepted model of "crew–aircraft" system, the reliability of crew operation during the simulator training is defined as a probability of its successful execution of work or a task at the specified stage of system functioning. Whereas the operator's errors are either the non-fulfilment of task or taking the prohibited action leading to the decrease of general safety of the system [12].

Carrying out the differential evaluation of the crew performance during the simulator training all erratic actions from their side are divided into several groups depending on the gravity of consequences:

1) "blunders" are such erratic actions of the crew, which during a real flight can lead to catastrophic, emergency or dangerous situations;
2) "errors" – during a real flight such erratic crew's actions can lead to the complication of flight conditions or aggravation of the situation up to a dangerous or even an emergency situation;
3) "incorrect actions" are the erroneous crew actions, which in a real situation cannot immediately lead to the occurrence or aggravation of a special situation, but they can become

the reason of material damage or lead to the additional increase of psychophysiological load of the crew;

4) "inaccuracies" are deviations from the prescribed order of crew actions, which cannot lead to dangerous consequences.

Accordingly to five-grade scale "blunder", "error", "incorrect action" and "inaccuracy" correspond to marks "1", "2", "3" and "4".

Professional performance of flight personnel includes three principal kinds of functions to be performed, for which the quantitative evaluation is possible:

- aircraft piloting;
- operating aircraft systems;
- making decisions regarding flight profile change.

Thus evaluating the functional effectiveness of the crew it is expedient to carry out a separate evaluation of each kind of performance, and then, with due consideration of weighting coefficients, to assign a general estimate of the flight [13].

C. Analytical Model of Pilot Technique Evaluation

The model of the pilot's actions in the process of piloting we shall represent as [8]:

$$h(t) = W(p) + n(t), \tag{2}$$

where

$h(t)$ are control actions of the pilot;

$W(p)$ is a transfer function of the pilot known from the automatic control theory;

$n(t)$ is a random function overlaid on the regular composition of the control actions taken by the operator. It depends on input signal $x(t)$ characteristics.

With the prescribed algorithm of the pilot's actions $h(t)$ the output parameters of the model of closed loop ergatic "operator–vehicle–environment" system will be in a certain data field in accordance with expression (1):

$$\left.\begin{array}{l} M_{CO} \;\Rightarrow\; dx/dt = f(x, u, \omega, t) \\ M_{CD} \;\Rightarrow\; u = \phi(x_2, \ h, \ t) \\ M_{HPM} \Rightarrow\; h = <x_1, \ m, t> \end{array}\right\} \tag{3}$$

for all: $x_1, x_2, x \in X$; $u \in U$; $\omega \in W$ in $t \in T = (t_k - t_0)$ interval,

where M_{CO}, M_{CD}, M_{HPM} correspondingly are the models of control object, control devices and "operator – activity means"; t_0, t_k correspondingly are initial and finite times of ES operation.

Pilot in the "operator–vehicle–environment" ES structure chooses concrete control aims $m_k \in M$, analyses the current state of the object $x(t)$, forms h – control action taking into account the occurred situation ω, evaluates the results of his own action. The algorithm of his actions is repeating. As a result of execution of the algorithm of h – actions by the pilot the aircraft is being transferred from initial $x = x(t_0)$ to finite state $x = x(t_k)$.

Performing the task m_k, the pilot may choose and realize a multitude of algorithms h – actions, but among them there exist only a definite h_n class ensuring the achievement of the finite aim in the concrete operating conditions ω_n.

Consequently the pilot's error while operating within "operator–vehicle–environment" ES will be defined as a condition expressing the mismatch of h – controls executed in the current n situation:

$$h \notin \{ h_n \}, \quad \omega_n \in W, \tag{4}$$

where $\{ h_n \}$ is a multitude of algorithms corresponding to n situation and m_k aim.

Executing a concrete algorithm of h – actions the pilot shall not admit the parameters falling outside the prescribed constraint zone in space:

$$Q_x \subset |x_{\mathrm{au}}, x_{\mathrm{ap}}|, \tag{5}$$

where x_{au}, x_{ap} are the upper and the lower limit of the constraint system for the parameters characterizing the state of "crew–aircraft–environment" system in accordance with (3).

In the documents regulating aircraft flight operations, for the expected operating conditions W there is determined a Q_x range of flight parameter values allowed in accordance with safety conditions. Then the piloting accuracy (h_n – algorithms realization only) will be recorded as a necessary condition of flight safety ensuring:

$$x \in Q_x, \text{ for } \omega_n \in W, t \in T. \tag{6}$$

The quantitative evaluation of pilot techniques is carried out by means of standardizing the deviations of a considered parameter from the regulated value. In piloting it is possible to mark out two characteristic deviation cases.

If a regulated value is prescribed by a concrete value (for example, design take-off speed), the deviation is recorded as:

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

where x is an actual value of the analysed parameter; x_0 is a standardized value of the analysed parameter.

In the case when a standardized parameter lies in some domain of permissible operating values, the deviations are presented as a difference between the actual value of the parameter being analysed and its standardized minimum and maximum value:

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

where $x_{0\max}$, $x_{0\min}$ are permissible values of the analysed parameter.

Each deviation of parameter Δx is assigned a corresponding mark depending on the influence of this deviation upon the flight safety.

In a general case, with the five-grade scale, it is possible to mark out Δx_1, Δx_2, Δx_3, Δx_4 intervals, each of them should be assigned a corresponding estimation "excellent", "inaccuracy", "incorrect action", "error" or their interpretation in numbers. Differentiation of evaluation may also be carried out depending on the consequences caused by each definite deviation (see Fig. 3).
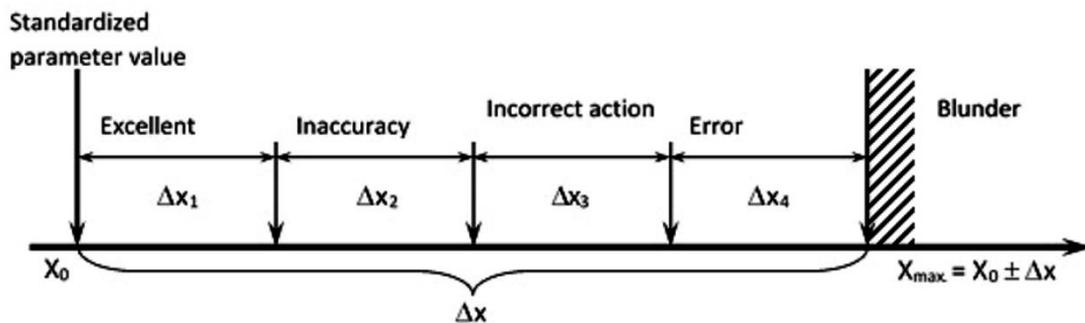

Fig. 3. Differential evaluation of *X* parameters deviation.

D. Analytical Model for Evaluating the Technology of Aircraft Systems Operation by the Crew

The control of aircraft systems has a discrete nature representing a set of consecutive operations. Each discrete action of the crew such as "on" or "off" is considered as an event in the chain of other events. Aircraft and its systems maintenance guide stipulates equipment and plane system operation procedures for each stage of the flight both in standard situations and in cases of systems failures and malfunctions.

Aircraft systems operation by the crew should be evaluated from two angles:
   a) evaluation of the "correctness" (appropriateness) of actions, for example, needlessly turning the systems "on" or "off";
   b) evaluation of "timeliness" of actions in relation to the systems, i.e. evaluation of the deviations of time and flight parameter values of turning the systems on and off from the values prescribed by the regulations.

The evaluation of the correctness of systems operation by the crew should be considered from the point of view of flight safety taking into account the accepted restrictions described by expression (5). In this case x_{au}, x_{ap} are the upper and the lower limit (determined in accordance with 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.

Necessary condition of accurate aircraft system operation by the crew can be recorded by analogy with expression (6).

Falling of at least one of the key parameters of crew action outside the limits of the specified region of limitations shall be regarded as an error made by the crew. Similarly to the case of pilot techniques evaluation, the differential evaluation of crew errors is carried out depending on the consequences.

Evaluating the timeliness of crew actions it is necessary to apply the probabilistic approach [14]. A conditional probability of system failure consequences accommodation by the crew during the fixed period of time can be assumed as an index of action timeliness, which means the probability of task fulfilment in the period of time $\tau \leq t_p$ where t_p is a time limit, and falling outside this time limit is considered to be an error. For example, having determined t_p and knowing the distribution law of the random variable of system failure accommodation time t_a, it is possible to determine the probability of timeliness P_{cb}:

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

(7)

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

For separate systems it is possible to prescribe a permissible range of time values from t_{pmin} to t_{pmax}, in which it is required to perform a necessary action with a system. In this case the failure accommodation timeliness probability formula (7) takes on the following form:

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

(8)

Crew's non-performance of the required action with the system up to the limiting time value t_{pmax}, as well as the performance of the specified actions earlier than t_{pmin} should be assigned a corresponding estimate depending on the consequences caused by this deviation from the limitations. If necessary the crew's actions in relation to the systems in the time interval from 0 to t_p can be also evaluated differentially (see Fig. 4).
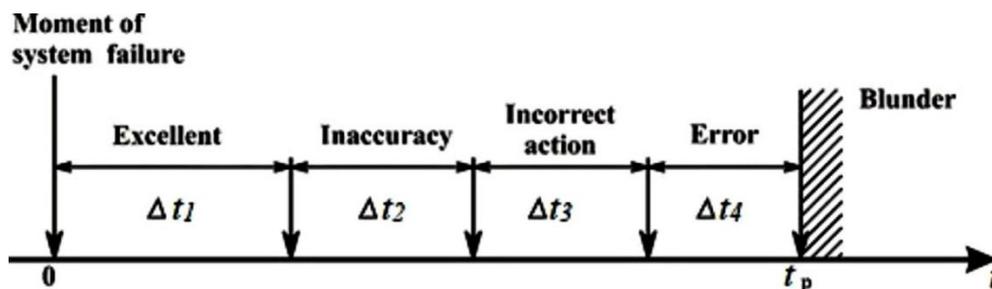

Fig. 4. Evaluation of the timeliness of crew actions when operating aircraft systems.

For this purpose, with a five-grade evaluation system, it is necessary to mark out time intervals Δt_1, Δt_2, Δt_3, Δt_4, each of them should be assigned a corresponding estimate "excellent", "inaccuracy", "incorrect action", "error" or their corresponding interpretation in numbers from "5" to "2". The differentiation of marks should also be performed depending on the consequences, which may be caused by the delay of actions taken by the aircraft crew [15].

E. Analytical Model for Evaluating Vehicle Operator's Decision-Making

The regulating documents contain the parameters of aircraft motion, the condition of aircraft systems, and ambient conditions for each stage of flight, which guarantee a safe continuation of the flight according to the designed scenario. The range of limitations Q_x of the parameters characterizing the flight is at the same time described by expression (5).

We shall present the necessary condition of aim m_e attainment – the continuation of flight according to the prescribed scenario as:

$$x_e \in Q_x \ \text{ for } \ \omega \in W_e \, , \, t \in T_e, \tag{9}$$

where T_e is a time of a certain flight segment; W_e are the ambient conditions determining the safe implementation of the flight at the prescribed segment.

For the given limitations, the pilot in the "crew–aircraft" ES structure forms the control actions h_e ensuring the attainment of the control aim m_e for the given segment of flight:

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

Falling of at least one of the key parameters outside the limits of the specified constraint zone (9):

$$x_{ea} \notin Q_x,$$

shall be regarded as the necessity of setting a new piloting aim m_{ea} by the crew – a flight profile change. To attain the new aim the crew forms a new control action h_{ea} taking into consideration the appeared situation x_{ea}:

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

As a result of the pilot's performance of h_{ea} actions the aircraft is being transferred from the initial state $x = x(t_e)$ to a new state $x = x(t_{ea})$, which corresponds to the change of flight profile.

If the actions performed by the aircraft pilot refer to class h_e, which does not correspond to the appeared x_{ea} situation, their realization at the given flight stage 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 corresponding to expression (9) is still existing. Depending on the gravity of possible consequences the crew's decision-making error will be evaluated differently.

IV. CONCLUSION

The offered mathematical model of vehicle operator functional effectiveness is universal, which gives the opportunity to create on its basis the systems of objective control and evaluation for vehicle simulators of different kinds. The developed adaptive algorithms of control and evaluation of operator performance can be applied in interactive automatic training systems.

REFERENCES

[1] D. O'Hare, *Human Performance in General Aviation*. ISBN 0-291-39852-9. Ashgate. 1999. https://doi.org/10.4324/9781315252995

[2] A. E. Diehl, "The effectiveness of training programs in preventing aircrew error", Paper Presented at *the 22nd International Seminar International Society of Air Safety Investigators,* Canberra, Australia, November 1991, pp. 640–656.

[3] R. Jensen, C. Tasoluk, H. Marshall, and M. Sanders, "FCS Intelligent Structured Training – Experimental Results and Future Applications", in *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2005*, vol. 2005 (Conference Theme: One Team. One Fight. One Training Future), pp. 52–63.

[4] J. A. Kukushkin, A. B. Bogomolov, and V. M. Usov, "Kompjuternie metodiki kontrolja nadeznosti professionalnoj dejatelnosti aviaspecialistov", in *XII konferencija po kosmiceskoj biologii i aviakosmiceskoj medicine*, Moscow, 10–14 June 2002, pp. 198. (in Russian)

[5] V. V. Kozlov, J. J. Kisljakov, and V. I. Dudin, "Sozdanie avtomatizirovannoj obucajushej sistemi dejstvijam v osobih situacijah poleta na osnove rezultatov rassledovanija aviacionnih proishestvij i incidentov", in *XII konferencija po kosmiceskoj biologii i aviakosmiceskoj medicine*, Moscow, 10–14 June 2002, pp. 175. (in Russian)

[6] I. P. Serduk, "Eksperementalnie issledovania effektivnosti algoritmov ocenki dejatelnosti ekipaza transportnogo samoleta", *Problemi bezopasnosti poletov*, Moscow, vol. 4, 2004, pp. 3–13.

[7] A. P. Prokofjev, *Nadezhnost i bezopasnost poletov.* Moscow: Masinostrojenie. 1985. (in Russian)

[8] P. V. Kartamishev and A. K. Tarasov, *Metodika letnogo obucenia*. Moscow: Transport, 1989. (in Russian)

[9] A. P. Prokofjev, "Funkcionalnaja effektivnost ekipaza", in *Letnaja dejatelnost ekipazej vozdusnih sudov*, Leningrad, OLAGA, 1986, pp. 3–11.

[10] A. Urbahs, M. Urbaha, and A. Cerkovnjuk, "Methodology of logistic organization and planning of Local Transport systems of intermodal transportation"*, Proceedings of International Conference Transport Means,* Kaunas University of Technology, Lithuania. 2005, pp. 239–241.

[11] International Civil Aviation Organization, *Accident Prevention Manual*. ICAO DOC 9422-AN/923. Montreal. November 1985. [Online]. Available: https://portal.mahan.aero/docs/docs/05-23-02-03/DOC%209422_en%20Accident%20Prevention%20Manual.pdf [Accessed: Mar. 14, 2017].

[12] Civil Aviation Authority, CAP 720. Flight Crew Training: Cockpit Resource Management (CRM) and Line-Oriented Flight Training (LOFT), 2002. ISBN 0 86039 8811. [Online]. Available: https://publicapps.caa.co.uk/docs/33/CAP720.PDF [Accessed: Mar. 30, 2017].

[13] A. Urbahs and V. Feofanovs, "Identification of the norms for the objective appraisal of the work of air crafts' crew based on the analysis of the flight information", in *Proceedings of International Conference Transport Means,* Kaunas University of Technology, Lithuania. 2005, pp. 203–206.

[14] A. Urbahs, M. Banov, and V. Turko, "Hypothesis of local zones with dependent fatigue damages accumulation", *Applied Mechanics and Materials*, 3rd International Conference on Mechanical and Aerospace Engineering, ICMAE, 7–8 July 2012, Paris, France, vol. 232, pp. 19-23, 2012. https://doi.org/10.4028/www.scientific.net/AMM.232.19

[15] M. A. Frenkel, A. J. Lesinskis, and V. V. Feofanov, "Obrabotka i analiz bolshih massivov poletnoj informacii s celju utocnenija normativov objektivnoj ocenki raboti ekipazej na KTS", Zaklucitelnij octet, Riga, RAU, 1993. (in Russian)

Viktors Feofanovs graduated from the Faculty of Mechanical Engineering, Riga Civil Aviation Engineering Institute in 1979. In 2008 he was awarded the Dr.sc.ing. degree by Riga Technical University. Since 2008 he has been a Senior Researcher at the Institute of Aeronautics, Riga Technical University, and an Assistant Professor at the Faculty of Transport and Mechanical Engineering, Riga Technical University. From 1999 to 2007 – Lecturer at Riga Technical University; from 1992 to 1999 – Lecturer at Riga Aviation University; from 1979 to 1992 – Engineer and Senior Researcher at Riga Civil Aviation Institute.

His fields of research: aeronautics, computer-aided training system, aerodynamics, transport systems and logistics.

Address: Institute of Aeronautics, Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, Lomonosova 1A, k-1, Riga, LV-1019, Latvia.

Phone: +371 67089990

E-mail: Viktors.Feofanovs@rtu.lv