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OBJECTIVE MONITORING SYSTEM FOR EVALUATION OF HELICOPTER CREW SCILLS

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ABSTRACT

The paper dwells on the problem of monitoring crew training progress on the helicopter flight simulators and offers objective criteria for the progress evaluation. The authors suggest separate evaluation of the piloting technique and mission effectiveness. The Flight Manual (FM) serves a crucial source to evaluate piloting procedures with special attention paid to operational limitations and recommendations. A dedicated software enables registration of every breach of the FM requirements, limits or inobservance of recommendations in the following areas:

- relative intensity of the breach;
- duration of the breach;
- the fault event frequency;
- hazardous effect of the breach.

A vast data on flight incidents & accidents with the Russian-origin civil and military helicopters have been used to make up a representative expert system. Another objects of piloting evaluation are the accuracy of sustaining established flight parameters and spectral density of control levers movements, that is laboriousness of piloting.

Elaborated with the statistics and frequency analysis and expert judgments, the system determines values of the objective criteria for the trainees' progress analysis. The computer-based analysis and evaluations are given for the Mi-24 crews simulator training both for standard operations and in emergencies due to engines and directional control failures.

1. GENERAL

It is a well-known fact that simulator training is traditionally led by instructors and these instructor-led sessions feature a number of drawbacks as far as training control and progress assessment methods are concerned, namely:

- need for a few highly professional instructors possessing guidance skills;
- subjectivity of trainees progress evaluation due to differences in instructors qualification, individual background, and specific personal psychophysiology;

- incapacity of human beings to monitor and control all trainees' actions and procedures simultaneously (instructors typically miss up to 40 % errors of the trainees).

In order to overcome some of the drawbacks, flight simulators are equipped with video and audio recorders that continuously register "flight" data and other parameters check to monitor, store the recorded data as long as desired, and offer a playback capability for further debriefings and as examples for other trainees.

From the experience gained at training sessions instructors complain about complexity and laboriousness of the "manual" monitoring and emphasize the necessity for introduction of computer-based objective monitoring and analysis aids to set the instructor free from continual watching the instruments thus enabling a broader instruction capability during the training session.

The present work briefly addresses general principles of the computer-based system developed for objective express analysis of piloting skills acquired at training and tested on the Mi-24 full-mission simulator.

This Express Analysis of Trainee Progress (EATP) is a dedicated computer-based system providing recording, analysis, and evaluation of helicopter systems availability and pilots/crew procedures.

EATP offers a resulting index whose value is indicative of pilot's ability to cope with the assigned task or mission.

The index value comprises a number of components each one corresponding to a certain stage of flight, namely pre-flight preparation, taxiing, hovering, takeoff, enroute flying, maneuvering, landing approach, landing, etc. Flight stages are characterized by flight conditions (regimes), and the latter in their turn comprise certain parameters typical of helicopter attitude and functional status as well as of "correctness" and relevance of pilot's actions.

2. COMPLEX CRITERION OF TRAINING EFFECTIVENESS

Evaluations of pilot's actions at simulated flying are done through the following principal characteristics:

- meeting flight safety requirements, including emergency procedures at failures of vital helicopter systems;
- piloting quality;
- structure of control movements;
- mission and procedures effectiveness subject to the special purpose (firefighting for civil rotorcraft or weapons application for combat helicopters, etc.);
- psychophysiologic tension of the trainee under monitoring.

The flight safety requirements are met mainly through precise observance of flight limitations and piloting instructions of the Flight Manual for a particular type of the helicopter. This safety criterion U_S is determined by a dedicated piloting purity criterion and based on the Flight Manual content and recorded flight parameters.

Piloting quality is characterized by criterion U_Q and depends on accurate holding on the given flight parameters within the assigned ranges at every flight stage or piloting task.

Mission effectiveness and particularly combat effectiveness U_M is evaluated by registering accuracy of aiming guided/unguided missiles, avia bombs, other standard weapons and consequent hitting the targets.

The psychophysiologic tension is usually evaluated with the use of dedicated equipment registering pulse and breathing rates, volume of pulmonary ventilation, as well as attention reserves and supplying the data to the indicators and printers. The better proficiency the less stress, which means we can judge the acquired skills and progress by reduced tension of the trainee at a simulated flight. However besides objective biological data, the pcychophysiologic tension of a trainee depends on his/her personal physical and physiological peculiarities in response to the training challenge as well as on a number of other poorly explored factors hard to account for. That is why at the first stage of the study the authors neglected this criterion.

Available crew instruction techniques are based on a 4-grade scale (“excellent”, “good”, “satisfactory”, and “bad” marks) with training standards and skill levels corresponding to each mark. Evaluation criteria and standards employed for this objective monitoring system are also based on the established requirements.

Evaluation of a flight mission quality is typically done by the grade-point average, where the excellent mark corresponds to a grade point no worse than 4.6 and the bad mark stands for grade-point averages below 3.0. When several exercises comprise a flight mission each one is evaluated separately.

The numerical score of the training effectiveness (quality) W for a pilot is determined by the following equation:

$$W = 5 - gU_{\Sigma}, \qquad (1)$$

where U_{Σ} is an integral penalty point, g is a weight coefficient used to rate the formula (1) depending on the penalty structure under investigation.

In general the numerical score U_{Σ} is determined on the basis of additive criterion:

$$U_{\Sigma} = p_S U_S + p_Q U_Q + p_M U_M, \qquad (2)$$

where $p_S + p_Q + p_M = 1$ (3)

Relative weight-average influence of each basic criteria U_S, U_Q and U_M on the total U_{Σ} criterion of training effectiveness is determined by numerical value of weight numbers p_S, p_Q and p_M of the formula (2). The realization of the condition (3) presupposes normalization as well as rating of individual homogeneous criteria under investigation. The figures p_S, p_Q and p_M were received on the results after representative expert analysis with the assistance of the leading Russian helicopter pilots, both civil and military.

3. SAFETY CRITERION

Calculating the numerical score U_S swerves from maximum permissible values of check parameters that are of certain interest are calculated quantitatively according to both relative number and relative duration of each failure. In such a case the following interval estimations are used:

$$\bar{N}_{ij} = \frac{P_j}{\Delta P_j}, \bar{N}_{ij} \le 1 \qquad (4)$$

$$\Delta P_j = P_{j\max} - P_{j\max}, P_{j\min} \le P_j \le P_{j\max} \qquad (5)$$

$\bar{N}_{ij}$ – relative piloting error;

$\bar{M}_{ij}$ – rise speed of the error intensity;

P_j – running value of the parameter under specification;

ΔP_j – domain of existence (variation range) of the parameter under investigation when its specified value is broken;

i – index number of the flight stage;

j – index number of the parameter under specification.

$$\bar{U}_{ij} = K_{ij} \frac{\int_{t_1}^{t_2} \bar{N}_{ij} dt}{t_2 - t_1} \int_{t_1}^{t_2} \bar{M}_{ij} dt \qquad (6)$$

where $\bar{U}_{ij}$ – specific weight of the j-th piloting error at the i-th flight stage;

K_{ij} – the error danger coefficient at the current flight stage and regime;

t_1, t_2 – the current time of the error start and ending;

$\frac{\int_{t_1}^{t_2} \bar{N}_{ij} dt}{t_2 - t_1}$ – average relative piloting error on a time of the error;

$\int_{t_1}^{t_2} \bar{M}_{ij} dt$ – error intensity (measure of error result assigned according to Flight Manual).

The danger coefficient values K_{ij} have been obtained by verified methods of math statistics and expert analysis of the flight safety database collected on helicopters Mi-2, Mi-8, Mi-24 during their wide-scale operation from 1980 to 2005. Events determining the danger coefficient are graded to fatalities, accidents, major incidents causing damage to the helicopter or no damage, minor incidents, adverse flight environments.

At a persistent error/breach of a limitation:

$$U_{ij} = \sum_{k=1}^{n} p_k \bar{U}_{ijk} \qquad (7)$$

U_{ij} – cumulative piloting error at the current flight stage;

p_k – repeatability factor for this particular error:

$$p_k = 1 + 0.1(k-1), \qquad (8)$$

$k = 1, 2, ..n$ – index number of a certain error at a current stage of flight.

$$U_j = \sum_{i=1}^{s} U_{ij} \qquad (9)$$

U_j – cumulative piloting error at all registered flight stages at the current training session (flight), $s = 1, 2, ..s_{\max}$ – number of registered flight stages.

$$U_S = \sum_{j=1}^{r} U_j \qquad (10)$$

U_S – cumulative error of the current flight; r - total number of considered errors.

The express-analysis algorithm is worked independently for each registered breach of FM (piloting error) as well as for every simulated emergency situation according to formulas (4)…. (9) with a number of additional cumulative operators and logical conditions.

4. PILOTING QUALITY

Piloting quality is characterized by accurate holding of specified flight parameters at certain flight stages or at certain piloting technique exercises. Piloting quality also depends on energy cost of the trainee spent to maintain the desired parameters. Simulator piloting quality evaluation principles are similar to those adopted for real aircraft flying and are thoroughly derived in relevant practice guidelines on flight training.

As standard reference values are taken parameters of the FM or set by an experienced flight instructor relying on his personal experience or statistical data obtained from real and simulated flights. Along with pre-assigned constant values some standard variation laws can be used as reference for the check parameters (a well-known principle of experienced pilots “Do as I do!”). As examples can be employed helicopter acceleration or deceleration from the initial to final speed of flight at a constant flight altitude, or an accurate banked turn at a constant bank angle, flight altitude and speed, or precise hovering over a specified spot, etc.

The following normalized mean square deviation of a parameter x_{ik} from its specified value x_{si} at a k-th stage of flight serves a statistical index to characterize the accuracy of a check parameter hold during time interval $[0, T_k]$:

$$U_{Ai} = X_i \frac{1}{T_k} \int_0^{T_k} \left[x_{ik}(t) - x_{si} \right]^2 dt , \qquad (11)$$

T_k – time duration of an exercise (maneuver).

The normalizing factor X_i is chosen so that the check parameter deviation corresponding to the unsatisfactory (bad) mark of the conventional training techniques should be equal to 1.

The S_i signal power, $S_{fi}(f)$ power spectrum characteristic is taken to be the energy costs of the i-th control (mainly the cyclic pitch control stick).

$$S_i = \int_0^{f_{\max i}} S_{fi}(f) df \qquad (12)$$

Despite similar integral indices, different pilots demonstrate significantly different frequency power spectra (fig. 1). Noteworthy, that “narrow” and “low” relative intensity maxima in frequency, i.e. less S_i signal power values are characteristic of better control inputs of the pilot.

The energy costs U_{Ei} is determined as control input power S_i normalized to 1:

$$U_{Ei} = \frac{S_i}{S_{\max i}}. \qquad (13)$$

$S_{\max i}$ corresponds to the maximum admissible energy costs estimated statistically.

The total piloting quality score U_Q also accounts for accuracy of the check parameters hold U_A and the energy costs U_E:

$$U_Q = g_A U_A + g_Q U_Q, \qquad (14)$$

where $U_A = \frac{1}{m}\sum_{i=1}^{m} U_{Ai}$, (15)

m is number of check parameters,

$$U_E = \frac{1}{n}\sum_{i=1}^{n} U_{Ei}, \qquad (16)$$

n is the number of controls under analysis.

The weight coefficients g_A and g_Q of the additive criterion U_Q are determined from expert evaluation similar to values of p_S, p_Q and p_M in expression for U_Σ.

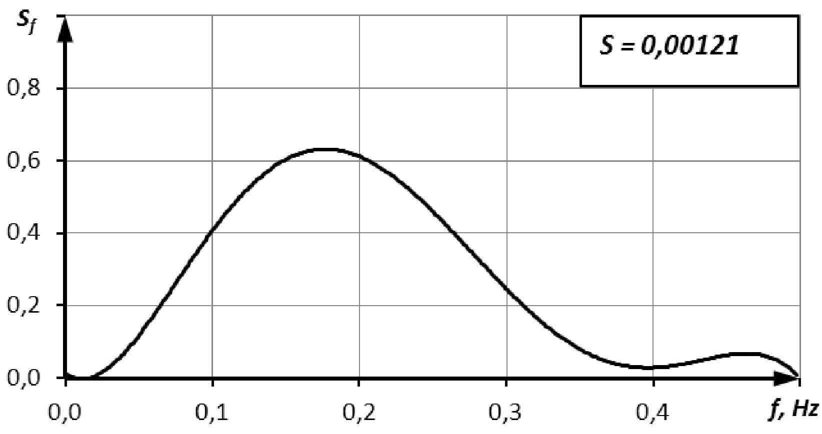
5. INTRODUCTION INTO PRACTICE AND VERIFICATION

The suggested assessment procedure aims at objective evaluation of crew's proficiency progress. It has been realized as a dedicated software package built in the Instructor Operating Station (IOS) software complex of the Mi-8 and Mi-24 full flight and full mission simulators.

An example shown in figure 2 presents part of the report table generated by EATP on the results of a trainee' Mi-24 simulated flight.

The complex criterion of training effectiveness is to comprise the control accuracy, piloting quality, and mission effectiveness components now proved, as well as trainees' psychophysiology to be developed as further elaboration of the EATP system.

A



B

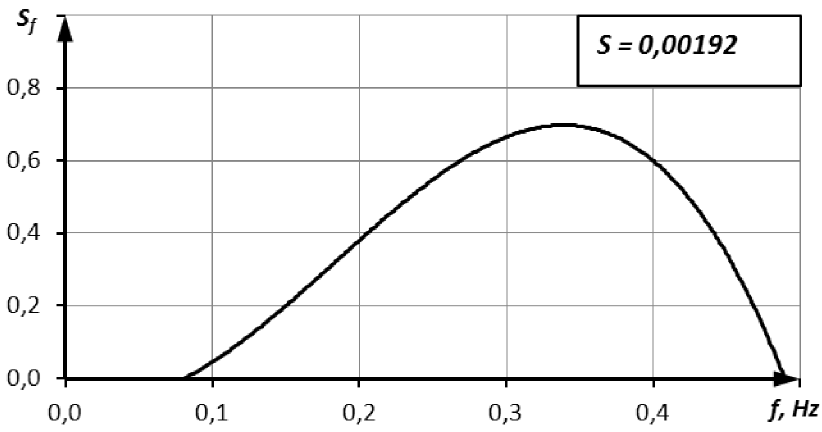


Fig. 1. The cyclic pitch control stick power spectrum in the roll channel at exercise “square 50 m × 50 m” at flight altitudes below 10 m. Data obtained from the Mi-24 simulated flights done by cadet pilots of different qualification (variants A and B). S is the signal power (area under the curve $S_f(f)$).

Messages

Start	End	Message	Duration	Flight stage	Number	Flight parameters	Estimation
0:01:33.880	0:01:37.460	Landing with extra high vertical speed	0:00:03.580	Landing	1	Hg = 1.3÷2.6 m V = 5.1÷7.2 km/h Vy g = -2.5÷-0.4 m/s	0.010
0:10:04.420	0:10:05.410	Extra high roll	0:00:00.990	Take off	4	Pitch = -19.1÷-6.9 ° Hg = 14.6÷15.2 m V = 15.4÷22.1 km/h	0.090
0:22:38.350	0:22:39.080	Error in steep climb end	0:00:00.730	Steep climb	1	V = 16.4÷18.1 km/h Hg = 51.0÷51.3 m Roll = 2.3÷3.9 °	0.080
0:30:12.560	0:30:20.830	Extra high roll	0:00:08.470	Landing	5	Pitch = -17.2÷20.7 ° Hg = 0.0÷15.4 m V = 9.4÷87.7 km/h	0.440

Fig. 2. Part of the flight report table on safety criterion at exercise “Pilotage in zone” done by trainee of initial level skills.