DEVELOPMENT OF ENGINEERING-ERGONOMIC REQUIREMENTS FOR DESIGN OF MULTI-PHASE CONTROLS FOR HELICOPTERS.

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Abstract

The experimental data of comparative ergonomic evaluation of standard and multi-phase controls is given. At the present time the world's helicopter industry is dealing with development of fly-by-wire control systems with multiple-axis controls integrated into the single control stick aimed at increase of automation level, reduction of complexity by learning, reduction of production costs, ergonomics improvement. The ultimate goal is to improve flight safety and increase competitiveness.

Keywords: Ergonomics, multi-phase controls, evaluation methodology, flight safety, side stick controls, fly-by-wire.

1. METHODOLOGY

In order to determine efficiency of task solutions of piloting with multi-phase controls was conducted the experimental comparative evaluation as opposed to standard controls. Comparative ergonomic evaluation of efficiency of task solutions of piloting with the use of standard controls and multi-phase controls in the conditions of test bed simulation was conducted in two stages.

In the first stage of ergonomic evaluation was conducted simulation of helicopter control activity conditions during solution of flight missions with different levels of complexity with the use of standard controls and multi-phase controls.

Herewith were simulated the following flight modes:

- take-off;
- hovering;
- horizontal locations;
- turns with different values of banking;
- helicopter-type landing.

In the course of work were conducted 174 experiments, 64 of them were conducted during piloting with standard controls, 110 – during piloting with multi-phase controls. The quantity of experiments conducted during piloting with different methods is represented in table 1.

Table 1

The quantity of modes conducted at different piloting methods

1	2	3	
No.	Name of flight mode	Quantity of experiments	
		With the use of standard controls	With the use of multi-phase controls
1	Take-off	4	5
2	Hovering	7	11
3	Three-sixty turn to the left	3	5
4	Three-sixty turn to the right	3	5
5	Forward translation	3	5
6	Aft translation	3	5
7	Left translation	3	5
8	Right translation	3	5
9	Acceleration-climb	3	5

1	2	3	
10	Level flight	12	24
11	Deceleration-acceleration	2	4
12	Left turn, banking 15 deg	3	5
13	Right turn, banking 15 deg	3	5
14	Left turn, banking 30 deg	3	5
15	Right turn, banking 30 deg	3	5
16	Deceleration	3	5
17	Landing	3	6

Following parameters of the process of helicopter control were evaluated:

- piloting precision;
- structure and quantity of control actions;
- pilot's attentional load during performing of different piloting modes;
- the possibility of performing the tasks with different level of complexity;
- the level of nervous-emotional tension in the process of control with application of standard controls and multi-phase controls.

For evaluation of piloting precision on a simulator with the use of standard controls and multi-phase controls the following flight parameters/variables were registered:

- banking;
- flight course;
- pitch;
- horizontal speed;
- height.

During evaluation of precision characteristics was determined the root-mean-square deviation of parameter from its mathematical expectation characterizing the accuracy of mode keeping within the given time interval.

For comparative evaluation of structure and quantity of control movements of the standard controls and multi-phase controls were registered the stick positions in longitudinal and lateral axis, as well as in directional axis and collective pitch axis. During analysis of registered data was used the mathematical method of results processing.

The main parameters were the standard controls positions, repositioning frequency with the following evaluation of their total quantity and reduction to the values of quantity of movements per minute, as well as the structure of movements with different standard controls dependently on flight conditions and modes performing.

The evaluation of attentional load over quantity of performed operations was carried out by means of «Physiolog» equipment. Pilot having free time during piloting process was solving additional task proposed by the device. On the device display panel was displayed the number of operations per minute and the quantity of correct solutions. The evaluation of attentional load over gaze direction was performed by means of video camera allowing registration of pilot's eyes position. Gaze direction was determined on the change of eyes position. The time spent for work with the device of additional task was calculated with respect to video registration data.

For comparative evaluation of pilot's nervous-emotional tension level in the process of piloting with application of standard controls and multi-phase controls was used digital storage of daily electrocardiogram (ECG) «ANNA FLASH 2000» intended for information retrieval in ambulatory conditions and uploading to the computer.

Storage device «ANNA FLASH 2000» stored ECG data in memory continuously over all engaged axes with compression without information loss.

The data obtained during conduction of experimental investigation was subjected to processing by means of computerized program «ANNA FLASH 2000».

Computer program automatically computed the numerical parameters, as well as plotted graphs on the basis of the whole consequence or chosen part of R-R intervals.

In the report of measurement of nervous-emotional tension level was made a note on event time and flight parameters.

At the second stage was evaluated the efficiency of crew activity in the process of helicopter piloting with the use of multi-phase controls. The evaluation was performed due to expert method with the involvement of flight personnel.

To obtain the competent expert evaluation with the involvement of flight personnel the developed questionnaire of crew activity efficiency ergonomic evaluation in the process of helicopter control was used.

In this questionnaire the experts were asked to evaluate the following parameters:

- efficiency of flight modes performing over banking, flight direction, pitch axes;
- the possibility of performing of the piloting process over two axes simultaneously;
- the possibility of performing of the piloting process over three axes simultaneously;
- expert's observations and suggestions.

The materials were processed for the purpose of experimental data integration, as well as obtaining of new information contained indirectly in the experts' answers. As the result of processing over every evaluated parameter the equidistributed estimate was calculated. Test pilots were involved into experiments.

2. RESULTS OF WORK

2.1. Results of Ergonomic Evaluation of Standard Controls and Multi-phase Controls with Respect to Piloting Quality in the Conditions of Test bed Simulation.

In table 2 are represented generalized materials of piloting quality evaluation in the conditions of test bed simulation at different stages of flight with the use of multi-phase controls.

Table 2

Piloting quality at different stages of flight with the use of multi-phase controls

Flight phase	Values of average deviation from the assigned flight parameters				
	in pitch, (± deg)	in banking, (± deg)	in heading, (± deg)	in speed, (± km/h)	in height, (± m)
Takeoff	0,22	1,23	0,16	0,59	-
Hovering	0,59	0,81	0,09	1,41	0,82
Level flight	0,25	0,17	1,54	1,13	1,93
Turn to the left 15°	0,56	0,26	-	4,76	8,40
Turn to the right 15°	0,70	0,35	-	4,66	7,86
Turn to the left 30°	0,97	0,70	-	5,56	7,70
Turn to the right 30°	0,58	0,50	-	3,23	7,17
Landing	0,48	0,89	0,11	1,62	-

From the table data it is seen that the values of average deviation from the assigned flight parameters with the use of multi-phase controls provide the high level of space attitude keeping. Average deviation values over pitch axis at the takeoff, hovering, level flight and landing phases amounted ± 0,22 deg, ± 0,59 deg, ± 0,25 deg and ± 0,48 deg, respectively. During performing of turns with different directions with banking angles of 15 and 30 degrees average deviation values over pitch axis amounted from ± 0,56 deg to ± 0,97 deg. At the phases of takeoff, hovering, level flight and landing the average deviation values over banking axis amounted ± 1,23 deg, ± 0,81 deg, ± 0,17 deg and ± 0,89 deg, respectively. During performing of turns with specified banking angle of 15 degrees the average deviation values over banking axis amounted ± 0,26 deg (left turn) and ± 0,35 deg (right turn). During performing of turns with specified banking angle of 30 degrees the average deviation values over banking axis amounted ± 0,70 deg (left turn) and ± 0,50 deg (right turn). Average deviation values over heading axis at the stages of takeoff, hovering, level flight and landing amounted ± 0,16 deg, ± 0,09 deg, ± 1,54 deg and ± 0,11 deg, respectively. At level flight mode the average deviation values from the assigned flight parameters over speed and height amounted 1,13 km/h and 1,93 m, what indicates the high quality of piloting with the use of multi-phase controls.

In the table 3 are represented generalized materials of piloting quality evaluation in the conditions of test

bed simulation at different stages of flight with the use of standard controls.

Table 3

Piloting quality at different stages of flight with the use of standard controls

Flight phase	Average deviation values from the assigned flight parameters				
	in pitch, (± deg)	in banking, (± deg)	in heading, (± deg)	in speed, (± km/h)	in height, (± m)
Take-off	0,17	0,74	0,63	0,69	-
Hovering	0,17	0,56	0,25	0,60	1,06
Level flight	0,50	0,37	0,22	2,76	3,56
Turn to the left 15°	0,86	2,04	-	5,64	8,26
Turn to the right 15°	1,45	0,69	-	7,24	10,92
Turn to the left 30°	1,36	0,36	-	5,75	14,66
Turn to the right 30°	1,72	0,97	-	6,24	8,09
Landing	0,18	0,69	0,62	0,52	-

From the table data it is seen that the values of average deviation from the assigned flight parameters provide sufficiently high level of space attitude keeping.

Average deviation values at the stages of takeoff, hovering, level flight and landing over pitch axis amounted ± 0,17 deg, ± 0,17 deg, ± 0,5 deg and ± 0,18 deg, respectively. During performing of turns with banking angles of 15 and 30 degrees the average deviation values over pitch axis amounted from ± 0,86 deg to ± 1,72 deg. At the stages of takeoff, hovering, level flight and landing average deviation values over banking axis amounted ± 0,74 deg, ± 0,56 deg, ± 0,37 deg and ± 0,69 deg, respectively. During performing of turns with banking angles of 15 and 30 degrees average deviation values over banking axis amounted from ± 0,36 deg to ± 2,04 deg. Maximum deviation values over banking axis during performing of turns was observed at left turns with banking of 15 degrees. Average deviation values over heading axis at the stages of takeoff, hovering, level flight and landing amounted ± 0,63 deg, ± 0,25 deg, ± 0,22 deg and ± 0,62 deg, respectively. At level flight mode and during performing of turns average deviation values from the assigned flight parameters over height amounted 3,56 m and 8,09 – 14,66 m, respectively. Average deviation values from the assigned flight parameters over speed at level flight mode amounted 2,76 km/h, what exceeds by 1,63 km/h the average deviation values during piloting with the use of multi-phase controls.

2.2 Results of Comparative Evaluation of Pilot's Attentional Load in the Process of Piloting with Standard Controls and Multi-phase Controls with Respect to Quantity of Performed Operations

In table 4 are represented the results of evaluation of pilot's attentional load in the process of piloting with standard controls.

Table 4

Pilot's attentional load with respect to quantity of performed operations in the process of piloting with standard controls

Flight mode	Time of work, sec	Total number of pressings	Number of correct pressings	Pause time, sec	% Attention reservs	% of correct pressings
Takeoff	39,7	11,7	9,7	3,5	12,0	83,3
Hovering	42,0	26,7	25,0	1,7	29,7	95,0
Level flight	22,7	8,3	7,3	3,0	16,7	89,7
Turn to the left 15°	115	42,3	39,7	3,0	17,2	93,80
Turn to the right 15°	110,7	34,3	34	4,6	16,0	98,80
Turn to the left 30°	63	16,3	15,7	6,9	13,9	96,80
Turn to the right 30°	61,7	17	16,3	3,7	14,3	96,10
Landing	35	12,3	12,3	2,9	18,3	100

In table 5 are represented the results of evaluation of pilot's attentional load in the process of piloting with multi-phase controls

Table 5

Attentional load with respect to quantity of performed operations in the process of piloting with multi-phase controls

Flight mode	Time of work, sec	Total number of pressings	Number of correct pressings	Pause time, sec	% Attention reservs	% of correct pressings
Takeoff	51,0	8,7	8,0	8,1	7,5	95,8
Hovering	34,7	11,3	10,7	3,5	16,0	95,6
Level flight	23,0	12,0	12,0	2,1	24,6	100,0
Turn to the left 15°	112	55,7	51,7	2,0	23,9	92,50
Turn to the right 15°	112,3	60,7	46	1,9	21,7	74,24
Turn to the left 30°	81	33,3	27,3	2,5	17,7	85,25
Turn to the right 30°	75	37,7	36	2,1	23,7	96,22
Landing	42,7	11,3	10,7	3,8	12,7	94,40

In diagram 1 is represented the data of comparative evaluation of pilot's attentional load in the process of piloting with standard controls and multi-phase controls with respect to quantity of performed

operations during performing of different piloting modes.

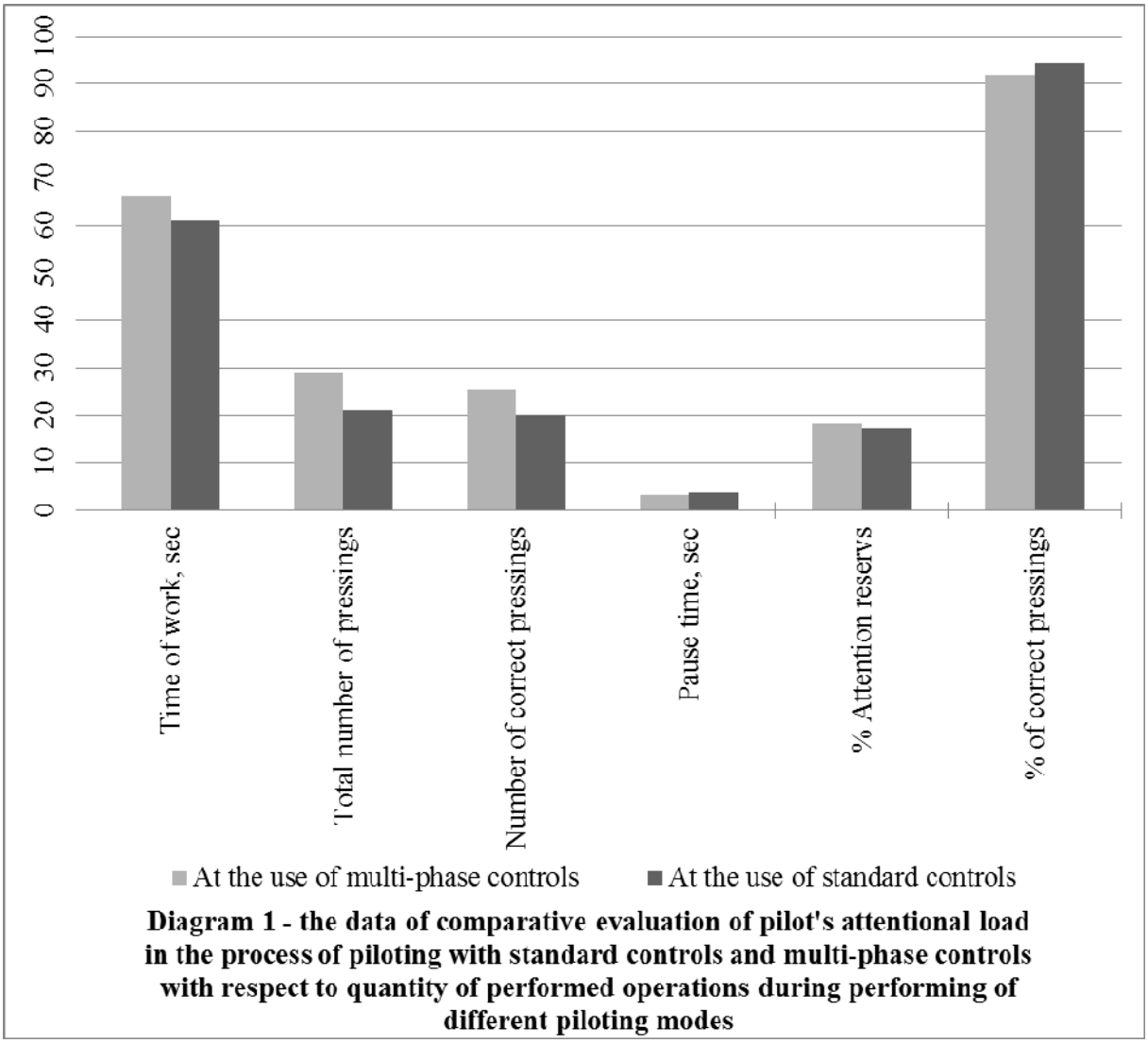

Diagram 1 - the data of comparative evaluation of pilot's attentional load in the process of piloting with standard controls and multi-phase controls with respect to quantity of performed operations during performing of different piloting modes

From the furnished data of diagram 1 it is seen that multi-phase controls have slightly higher average figures over all evaluated parameters almost at all piloting modes. Time of work with residual attention unit during use of multi-phase controls is for 3,2 % higher than for standard controls. The value of pressings total number with the use of multi-phase controls is for 1,6 % higher than during use of standard controls. The value of correct pressings with the use of multi-phase controls is for 1,06% higher as compared with the use of standard controls. Difference in values of pause time for multi-phase controls negligibly small and amounts 0,01% as compared to standard controls. Percentage ratio of work with residual attention unit during use of multi-phase controls is for 0,2 % greater than during use of standard controls. The number of correct pressings during use of multi-phase controls is for 2,2 % less than during use of standard controls.

According to the obtained data it is reasonable to make a conclusion that multi-phase controls over attentional load factor over the number of performed operations during performing of different piloting modes are almost identical to standard controls, and for most cases slightly exceed them.

2.3. Results of Comparative Evaluation of Pilot's Attentional Load in the Process of Piloting with Standard Controls and Multi-phase Controls with Respect to Gaze Direction

In table 6 is represented the data of evaluation of pilot's attentional load over gaze direction in the

process of piloting with standard controls and multi-phase controls.

Table 6

Pilot's attentional load during piloting with application of standard controls and multi-phase controls

No.	Flight mode	Time of work with residual attention, %	
		With the use of standard controls	With the use of multi-phase controls
1	Takeoff	10,2	3
2	Hovering	42,5	17
3	Turns	27,6	24
4	Landing	12,8	9

In diagram 2 is represented the data of comparative evaluation of attentional load over pilot's gaze direction during performing of piloting modes with different methods.

From the furnished data of table 6 and diagram 2 it is seen that during performing of «takeoff» mode with application of standard controls the time of work with residual attention amounts 10,2 % of total time of mode performing, what is for 7,2 % greater than during piloting with the use of multi-phase controls (3 %). At hovering mode the time of work with residual attention during piloting with standard controls amounted 42,5 % of total time of mode performing, and during piloting with multi-phase controls – 17 %. During performing of turns with different banking angles the time of work with residual attention during piloting with standard controls and with multi-phase controls amounted 27,6 % and 24 %, respectively. At landing during piloting with standard controls the time of work with residual attention amounted 12,8 % of total time of mode performing, and during piloting with multi-phase controls – 9 %.

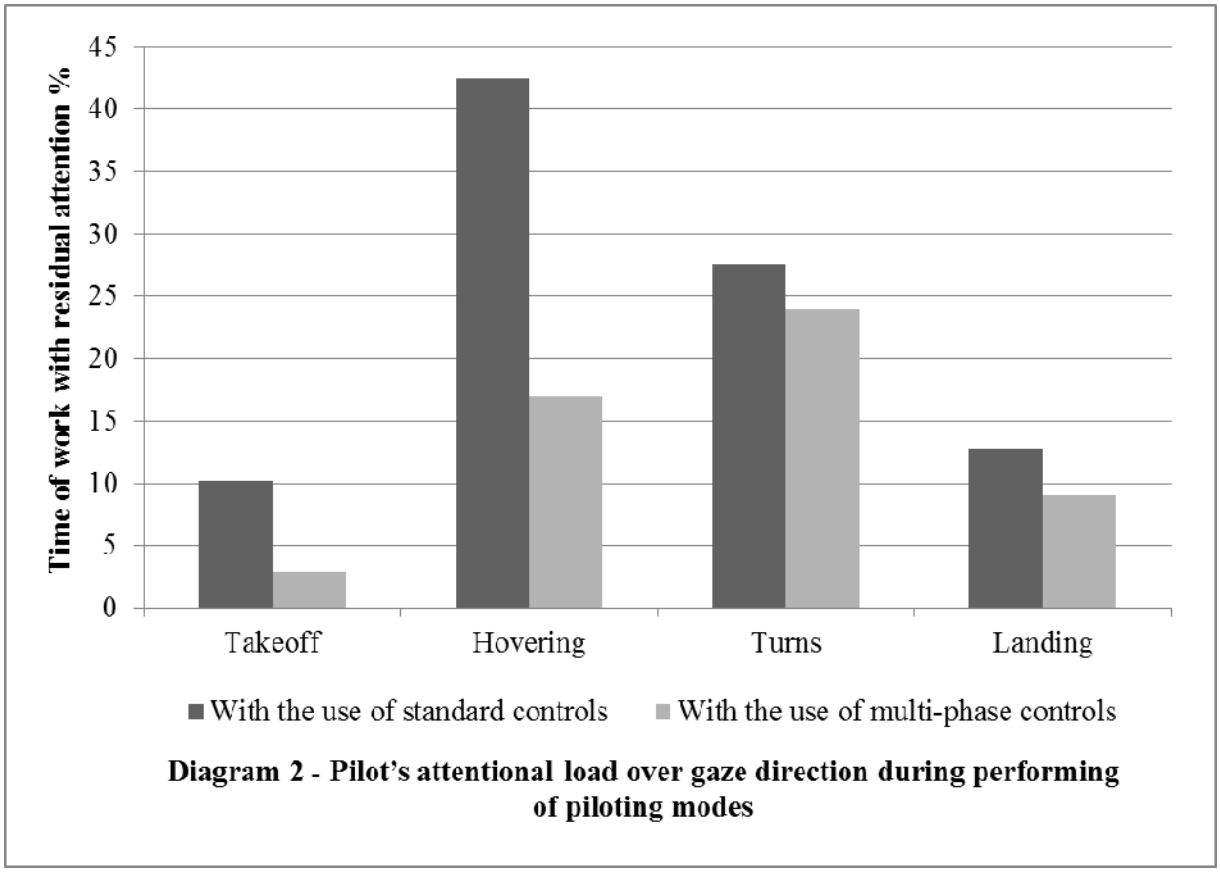

Diagram 2 - Pilot's attentional load over gaze direction during performing of piloting modes

2.4. Results of Comparative Evaluation of Nervous-emotional Tension Level in the Piloting Process with Application of Standard Controls and Multi-phase Controls

In table 7 and in diagram 3 is shown the level of nervous-emotional tension, expressed as a percentage of initial level of pilots' heartbeat rate during performing of different piloting modes with the use of standard controls and multi-phase controls. The initial level of pilots' heartbeat rate is obtained in calm conditions on ground.

The materials of furnished data show that performing of piloting modes (takeoff, hovering, level flight, turns with banking of 15 and 30 degrees and landing) with the use of standard controls causes essential pilot's tension as compared to piloting by means of multi-phase controls.

Table 7

Nervous-emotional tension level during piloting with the use of standard controls and multi-phase controls

1	2	3	
No.	Mode name	Change of heartbeat rate as compared to initial level (background at rest), %	
		With the use of standard controls	With the use of multi-phase controls
1	Takeoff	20,1	10,8
2	Hovering	17,7	14,7
3	Level flight	10,8	6,6

1	2	3	
4	Left turn banking 15 deg	12,7	6,9
5	Right turn banking 15 deg	10,3	6,1
6	Left turn banking 30 deg	12,7	7,7
7	Right turn banking 30 deg	12,2	6,9
8	Landing	15,5	6,6

The materials of furnished data show that performing of piloting modes (takeoff, hovering, level flight, turns with banking of 15 and 30 degrees and landing) with the use of standard controls causes essential pilot's tension as compared to piloting by means of multi-phase controls.

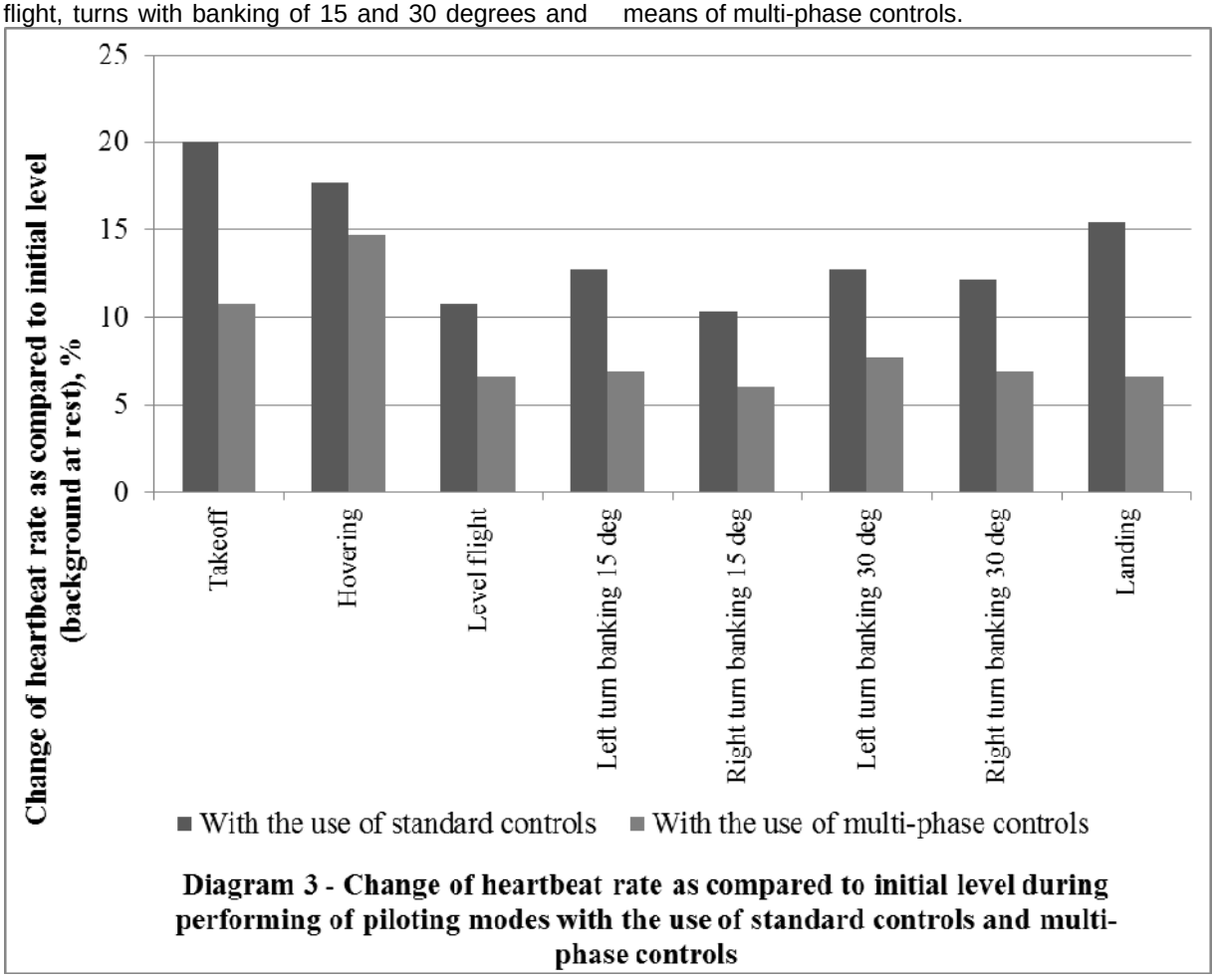

Diagram 3 - Change of heartbeat rate as compared to initial level during performing of piloting modes with the use of standard controls and multi-phase controls

So, at «take-off» piloting mode with application of standard controls Change of heartbeat rate as compared to initial level amounted 20,1%, and with the use of multi-phase controls – 10,8%. During performing of «Hovering» mode with the use of standard controls and multi-phase controls Change of heartbeat rate as compared to initial level amounted 17,7% and 14,7%, respectively. At level flight mode the nervous-emotional tension level expressed as a percentage of initial level of pilots' heartbeat rate heartbeat rate amounted 10,8% during piloting with standard controls and 6,6% with the use of multi-phase controls. During performing of turns with banking of 15 and 30 degrees with the use of standard controls the value under investigation amounted 10,3 – 12,7%, and during piloting with multi-phase controls 6,1 – 7,7%. At landing Change of heartbeat rate as compared to initial level during piloting with the use of standard

controls and multi-phase controls amounted 15,5% and 6,6%, respectively.

Thus, the nervous-emotional tension level with respect to data of Change of heartbeat rate as compared to initial level reflects the degree of complexity of piloting with application of standard controls relatively to piloting with the use of multi-phase controls. The greatest degree of manifestation of the nervous-emotional tension level during performing of piloting modes with the use of multi-phase controls was reported at modes of take-off and hovering.

2.5. Results of Questionnaire Survey on Ergonomic Evaluation of Efficiency of Crew Activity in the Process of Piloting with the Use of Multi-phase Controls

The results of judgmental ergonomic evaluation of efficiency of crew activity in the process of piloting with the use of multi-phase controls on 5-mark rating scale are represented in table 8.

Table 8

The results of judgmental ergonomic evaluation of efficiency of piloting with the use of multi-phase controls

No.	Evaluation parameter	Mean values of evaluation parameters
1	Efficiency of modes performing over banking axis with the use of multi-phase controls	4
2	Efficiency of modes performing over pitch axis with the use of multi-phase controls	4
3	Efficiency of modes performing over heading axis with the use of multi-phase controls	4
4	The possibility of performing of the piloting process over two axes simultaneously with the use of multi-phase controls	4,3
5	The possibility of performing of the piloting process over three axes simultaneously (banking, pitch, heading) with the use of multi-phase controls	3,67

From the furnished data it is seen that efficiency of modes performing over banking, pitch and heading axes with the use of multi-phase controls the expert evaluated as «well», assigning to the given parameters mark «4» (evaluated characteristics are good enough, but there are some comments). «The possibility of performing of the piloting process over two axes simultaneously with the use of multi-phase controls» evaluation parameter got the mark «4,3», what is, according to rating scale, close to value «evaluated characteristics are good enough, but there are some comments». It is worth mentioning that during piloting evaluation over every axis separately was obtained lower total mark than during piloting evaluation over two axes simultaneously. Presumably, it is connected with that the pilots have fully formed stereotype of piloting skills over two axes simultaneously (lateral and longitudinal), and separation of axes causes slight discomfort. The possibility of performing of the piloting process over three axes simultaneously (banking, pitch, heading) with the use of multi-phase controls was evaluated by experts as «3,67» points – «satisfactory».

In the process of conducting of questionnaire survey experts specified the following comments: «banking and pitch change angle rate is low», «it is necessary to restrict the angles of maximum banking and pitch because of slow work of actuating mechanisms», «performing of modes with turns causes being less attentive to control of stick control deflection over other axes». Herewith the experts marked in questionnaires that at great and fast changes of values, especially with sign change (+, -) occurs the decrease of control sensitivity due to damping lacks. In general, flight personnel mentioned that piloting with multi-phase controls doesn't cause great difficulties and will be easy utilized by the flight personnel of any level of training.

3. CONCLUSIONS:

Thus, as a result of conducted experiments it was established that the application of multi-phase controls provides the high level of aircraft space attitude keeping. Pilot's attentional load factor during piloting with the use of multi-phase controls provides backward level as compared to standard controls index. The indices of nervous-emotional tension

level during piloting with the use of multi-phase controls are lower than during use of standard controls. According to the results of questionnaire survey was obtained a favourable report of flight personnel on multi-phase controls application. Existing drawbacks are related to constructed-mechanical ones and can be corrected in the process of further development. In genera the application of multi-phase controls can fully exclude the use of standard controls, what will allow the transition to a new automation level and increase flight safety.