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# EXPERIMENTAL VALIDATION FOR THE TRAINING METHOD AND MATHEMATICAL MODEL OF THE PILOT SKILL FORMATION IN MAINTENANCE OF ATTITUDE ORIENTATION

**Summary.** In order to overcome the drawbacks in artificial horizon indicator (HI) of inside-in type (a view from an aircraft (A/C)), where pilots produce mistakes in maintenance of attitude orientation most of all, the authors offer a novel training method. The method is based on the hypothesis that the manipulative ability of a human visual system can be trained. A mathematical model for the data accumulation during the corresponding training procedure has been proposed. Construction, design and results of the model evaluation are presented in the article. The experimental results revealed the increase of the probability of faultless operation by the test group of up to 0,892, whereas the faultless operation probability of a control group was 0,726. Thus, the trainee-students have statistically increased the reliability for the maintenance of attitude orientation thanks to the proposed method, and the hypothesis was confirmed.

## 1. INTRODUCTION

The process of the spatial orientation percept formation is a complex element in a pilot training. Its formation demands purposeful preparation, while the corresponding technique is not fully explored nowadays [1-3].

Numerous theoretical studies [1-10] show that the most suitable kind of horizon indicator (HI) is *outside-out* (a view from ground) HI. However, most civil aircraft are equipped with *inside-in* kind of HI at present, which in critical cases can lead to spatial disorientation [2]. There are two ways to overcome this problem. The first method is to use a more advanced indicator that provides the pilot with information about A/C position with respect to a ground plane. The second one suggests development and implementation of new pilot training methods which allow pilots to form skills in maintenance of attitude orientation in a routine flight and abnormal cases including ones where A/C operates beyond its limitations.

## 2. METHOD

Following from the analysis of the literature and personal experience, the authors made an assumption that a visualization, where an A/C displayed on the simulator monitor is movable, dimensional and its empennage is turned to an operator while the “ground” is immovable (Fig. 1a), will help to improve skills stability in piloting for *inside-in* HI in difficult conditions. On this basis, a new training method was suggested.

In the first stage of the training, the piloting is performed on the simulator only with an A/C displayed on the monitor. In the next stages, it is performed using both the image of an aircraft and *inside-in* HI data (Fig. 1b). From the authors' point of view, this method must help trainee-students to form such visualization of the flight that would provide more stable spatial orientation skills during the flight.

a) b)

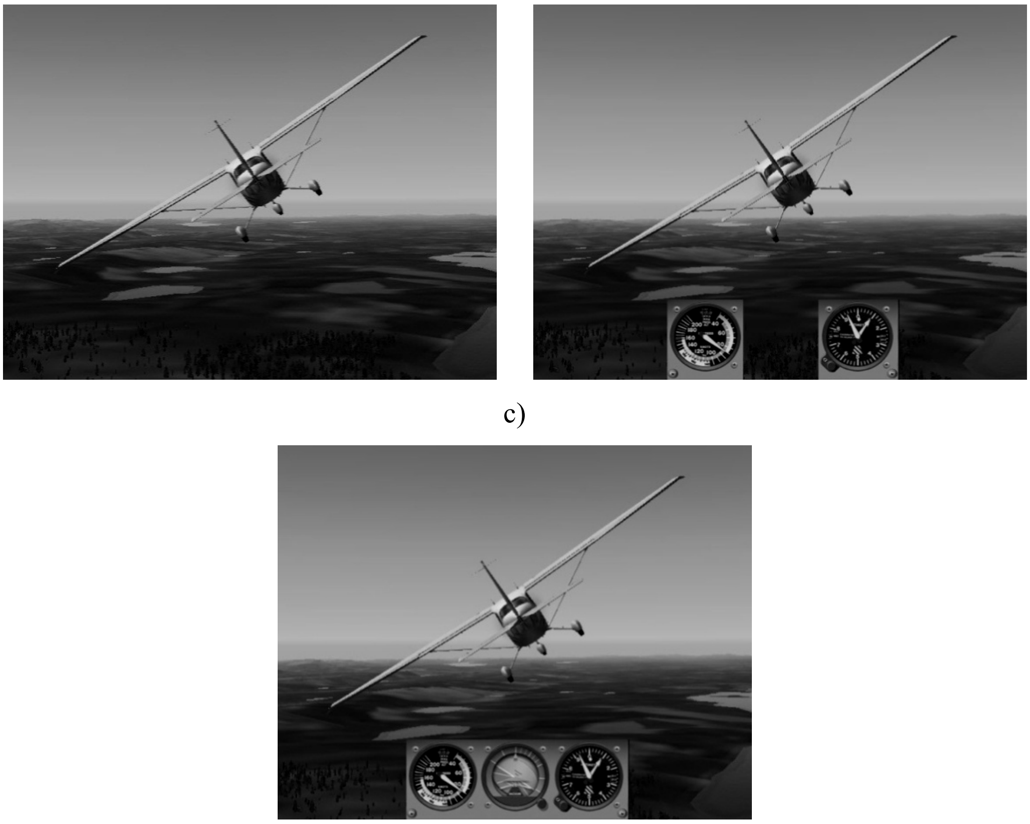


Fig. 1. Stages of experiment

**3. EXPERIMENTAL PART**

To verify the proposed hypothesis, a special program for an experimental group based on the use of *inside-in* HI was developed. It consisted of five tasks and was carried on the procedural simulators at St. Petersburg State University of Civil Aviation.

In the first task, the A/C displayed on the simulator's monitor is movable, dimensional and its empennage is turned to an operator, whereas the ground is immovable; one flight session lasts ten minutes (Fig. 1a).

In the second task, the A/C is controlled in a vertical plane (the image of the A/C is similar to that in the first task), i.e. the A/C performs flight maneuvers such as spin, rolling, and loop maneuvers; one flight session lasts fifteen minutes.

In the third task, control members (altitude and speed) of the flight mode are introduced additionally to the aircraft image (Fig. 1b); one flight session lasts fifteen minutes.

In the fourth task, artificial horizon indicators are added together with the aircraft image, altitude display and speed indicators (Fig.1c); there were three flight sessions of fifteen minutes each.

In the fifth task, piloting is performed with the help of navigation instruments, where only the control panel is displayed, and the image of an aircraft is not available; five flight sessions were conducted of fifteen minutes each.

The training program for procedural simulators adopted at present includes ground training, familiarization flight to the landing zone and cruising flights using navigation aids. Total training time is 27 hours. The training program offered by the authors lasts 2 hours and 40 minutes and is meant not as a substitution of existing program but as addition to it.

Based on duration of the tasks and the amount of provided information, a mathematical model for the accumulation of information with interruptions was developed. In the model description, we utilize the terminology originally formulated in [11]. The mathematical model was used to determine an optimal time to present the information.

Let us determine the amount of information in the pilot's memory after every task.

The equation describing the process of acquiring information in the first task is as follows:

$$\overline{I_1} = (1 - e^{-\overline{\tau_1}})/\overline{\tau_1}$$

where $\overline{\tau_1} = \frac{I_\Sigma}{R_1 T_1} = \frac{\tau_1}{T_1}$ is the ratio of coming of information presenting (in seconds) to the time constant in the first task; $R_1$ is the speed of the coming information in the first task; $T_1$ is the time constant in the first task.

Let us compute the total amount of the coming information:

$$I_\Sigma = m\, log_2 \frac{l}{\Delta l},$$

where $m$ is a number of the given instruments; $l$ is an effective length of instrument scale (in degrees); and $\Delta l$ is an error while reading the instrument (in degrees).

$$I_{\Sigma 1} = 1\, log_2 \frac{30}{2} = 3{,}33,$$

where $I_{\Sigma 1}$ is theamount of information coming in the first task.

Let us compute the speed of the coming information:

$$R = \frac{I_\Sigma}{\tau},$$

where $\tau$ is the time of information presenting (in seconds). Here τ is the duration of a task (in our case, it is 10 min)

$$R_1 = \frac{3{,}33}{600} = 0{,}0055$$

where $R_1$ is the speed of the coming information in the first task.

Let us calculate the time constant in the first task:

$$\mathrm{T} = \frac{a}{R^{1,1}}; \mathrm{T}_1 = \frac{2{,}6}{0{,}0055^{1,1}} = \frac{2{,}6}{0{,}0033} = 866{,}7$$

where $a$= 2,6 [11]; $\mathrm{T}_1$ is the time constant in the first task.

Let us calculate the ratio of incoming information to constant of time:

$$\overline{\tau} = \frac{\tau}{\mathrm{T}}; \quad \overline{\tau_1} = \frac{\tau_1}{T_1},$$

where $\overline{\tau_1}$ is the ratio of incoming information to the time constant in the first task.

The process of acquisition information in the first task is the following:

$$\overline{\mathrm{I}}_1 = \frac{(1 \quad e^{\;0,692})}{0{,}692} = \frac{1 \quad 0{,}501}{0{,}692} = 0{,}721.$$

The obtained value of the information acquisition process indicates that the duration of the task and the amount of the presented information were chosen correctly, and it is proved by a great number of experiments [11]. If one reduces the amount of the presented information, the operator's activity decreases. If one considerably increases the amount of the presented information, the operator's overloading occurs. Both changes of the amount of the information negatively influence the operator's information perception.

Now let us calculate forgetfulness of the received information after the first task. Let us calculate the speed of forgetfulness of the information:

$$R^* = \frac{I_\Sigma}{\tau^*},$$

where $\tau^*$ is time of forgetfulness of information, i.e. the time from the end of the task to the beginning of the next task (in seconds)

$$R_1^* = \frac{3{,}33}{300} = 0{,}011,$$

where $R_1^*$is the speed of forgetfulness of the information in the time from the end of the first task to the beginning of the first task (in seconds).

Let us calculate the time constant in the case of forgetfulness of information in the first task:

$$\mathrm{T}^* = \frac{a}{R^{*1,1}}; \mathrm{T}^*_1 = \frac{2{,}6}{0{,}011^{1,1}} = 371{,}4.$$

Let us calculate the ratio of information forgetfulness time to the time constant in case of forgetfulness of information in the first task:

$$\overline{\tau^*} = \frac{\tau^*}{T^*} \overline{\tau_1}^* = \frac{300}{371{,}4} = 0{,}808.$$

The process of forgetfulness of information is described by the following equation:

$$\overline{I_n}^* = \overline{I_{\infty n}} + \left(\overline{I_n} - \overline{I_{\infty n}}\right)e^{-\overline{\tau_n^*}},$$

where *n* is the number of task.

The value $I_\infty$ (the amount of information in memory after expiration of long laps of time) depends on the duration of the break between the tasks, and it increases from task to task, which is caused by accumulation of information in memory [11]:

$$I_{\infty 1} = 0{,}64;\ \overline{I_1}^* = 0{,}64 + (0{,}721 - 0{,}64)e^{-0{,}808} = 0{,}676.$$

where $\overline{I_1}^*$ is the amount of forgetfulness of information in memory after the first task.

The computations of the process of information acquirement for the next tasks were made by the following formula:

$$\overline{I_n} = \left(\frac{1-e^{-\overline{\tau_n}}}{\overline{\tau_n}}\right) + \left(1 - \frac{1-e^{-\overline{\tau_n}}}{\overline{\tau_n}}\right) * \overline{I_{n-1}^*}.$$

The numerical expressions for the following tasks are the same as in the first task. The computations for the second task are as follows:

$$I_{\Sigma 2} = 1\, log_2 \frac{360}{5} = 6{,}17,$$

where $I_{\Sigma 2}$ is the total amount of information coming during in the second task.

In this case, the effective scale length has increased up to 360 degrees. It is predefined by the fact that in the second task the A/C rotates about its axes by 360 degrees, i.e. it performs the flight maneuvers:

$$R_2 = \frac{6{,}17}{900} = 0{,}0069;\ \mathrm{T}_1 = \frac{2{,}6}{0{,}0069^{1,1}} = \frac{2{,}6}{0{,}004} = 650; \overline{\tau_2} = \frac{900}{650} = 1{,}38.$$

where $R_2$ is the speed of the coming information during in the second task; $\mathrm{T}_2$ is the time constant in the second task; $\tau_2$is the time of information presenting (in seconds) during the second task.

The process of information acquirement is of the following form:

$$\overline{I_2} = \left(\frac{1-e^{-1{,}38}}{1{,}38}\right) + \left(1 - \frac{1-e^{-1{,}38}}{1{,}38}\right) * 0{,}676 = 0{,}852.$$

Let us compute the forgetfulness of the received information for the second task:

$$R_2^* = \frac{6{,}17}{172800} = 0{,}000036;\ T_2^* = \frac{2{,}6}{0{,}000036^{\,1,1}} = 260000; \overline{\tau_2}^* = \frac{172800}{260000} = 0{,}665.$$

where $R_2^*$ is the speed of forgetfulness of the information after the second task but before the third one; $T_2^*$ is the time constant in case of forgetfulness of information in the second task; $\overline{\tau_2}^*$ is the ratio of information forgetfulness time to the time constant in case of forgetfulness of information in the second task.

The process of the information forgetfulness:

$$I_{\infty 2} = 0{,}55\ [8];\ \overline{I_2}^* = 0{,}55 + (0{,}852 - 0{,}55)e^{-0{,}665} = 0{,}705.$$

where $\overline{I_2}^*$ is the amount of information forget fullness after the second task.

The computations for the third task are as follows:

$$I_{\Sigma 3} = 3\,log_2 \frac{100}{5} = 12{,}9,$$

where $I_{\Sigma 3}$ isthe total amount of information coming in the third task.

In the third and the following tasks, the effective scale length is an average scale length among the three presented instruments:

$$R_3 = \frac{12{,}9}{900} = 0{,}014;\ T_3 = \frac{2{,}6}{0{,}014^{1{,}1}} = \frac{2{,}6}{0{,}009} = 288{,}9;\ \overline{\tau_3} = \frac{900}{288{,}9} = 3{,}115,$$

where $R_3$ is the speed of the coming information in the third task; $T_3$is the time constant during the third task; $\tau_3$ is the time of information presenting (in seconds) during the third task.

The process of the information acquisition is as follows:

$$\overline{I_3} = \left(\frac{1-e^{-3{,}115}}{3{,}115}\right) + \left(1 - \frac{1-e^{-3{,}115}}{3{,}115}\right) * 0{,}705 = 0{,}796,$$

where $\overline{I_3{}^*}$ – the amount of information forget fullness after the third task.

Let us calculate the forgetfulness of the received information:

$$R_3^* = \frac{12{,}9}{120} = 0{,}107;\ T_3^* = \frac{2{,}6}{0{,}107^{\,1{,}1}} = 30{,}6;\ \overline{\tau_3{}^*} = \frac{120}{30{,}6} = 3{,}922;$$

$$\overline{I_3{}^*} = 0{,}65 + (0{,}796 - 0{,}65)e^{-3{,}922} = 0{,}653,$$

where $R_3^*$ is the speed of forgetfulness of the information after the end of the third task and before the fourth task is started; $T_3^*$ is the time constant in case of forgetfulness of information during the third task; $\overline{\tau_3{}^*}$ is the ratio of information forgetfulness time to the time constant in case of forgetfulness of information in the third task.

In order to complete the analogy, let us perform computations for the first part of the fourth task:

$$I_{\Sigma 4.1} = 4\,log_2 \frac{82}{10} = 12{,}16;\ R_{4.1} = \frac{12{,}16}{900} = 0{,}01;\ T_{4.1} = \frac{2{,}6}{0{,}01^{1{,}1}} = \frac{2{,}6}{0{,}006} = 433{,}3;$$

$$\overline{\tau_{4.1}} = \frac{900}{433{,}3} = 2{,}07.$$

The process of the information acquisition is defined as follows:

$$\overline{I_{4.1}} = \left(\frac{1-e^{-2{,}07}}{2{,}07}\right) + \left(1 - \frac{1-e^{-2{,}07}}{2{,}07}\right) * 0{,}653 = 0{,}8.$$

Let us calculate the forgetfulness of the received information:

$$R_{4.1}^* = \frac{12{,}16}{172800} = 0{,}00007;\ T_{4.1}^* = \frac{2{,}6}{0{,}00007^{\,1{,}1}} = 173333{,}3;$$

$$\overline{\tau_{4.1}{}^*} = \frac{120}{30{,}6} = 0{,}9;\ \overline{I_{4.1}{}^*} = 0{,}57 + (0{,}8 - 0{,}57)e^{-0{,}9} = 0{,}664.$$

Let us perform calculations for the second part of the fourth task:

$$I_{\Sigma 4.2} = 4\,log_2 \frac{82}{10} = 12{,}164;\ R_{4.2} = \frac{12{,}16}{1800} = 0{,}006.$$

In this case, a decision was made to combine the duration of two tasks (30 minutes instead of two tasks,15 minutes each) as they were made sequentially without an interruption and have the same speed of the coming information:

$$T_{4.2} = \frac{2{,}6}{0{,}006^{1{,}1}} = \frac{2{,}6}{0{,}003} = 866{,}7;\ \overline{\tau_{4.2}} = \frac{1800}{866{,}7} = 2{,}07.$$

The process of information acquisition is as follows:

$$\overline{I_{4.2}} = \left(\frac{1-e^{-2{,}07}}{2{,}07}\right) + \left(1 - \frac{1-e^{-2{,}07}}{2{,}07}\right) * 0{,}664 = 0{,}81.$$

Let us compute the forgetfulness of the received information:

$$R_{4.2}^* = \frac{12{,}16}{86400} = 0{,}0001;\ T_{4.2}^* = \frac{2{,}6}{0{,}0001^{\,1{,}1}} = 86666{,}7\ \overline{\tau_{4.2}{}^*} = \frac{120}{30{,}6} = 0{,}997;$$

$$\overline{I_{4.2}{}^*} = 0{,}59 + (0{,}81 - 0{,}59)e^{-0{,}997} = 0{,}672.$$

The computations for the first part of the fifth task are as follows:

$$I_{\Sigma 5.1} = 3\,log_2 \frac{100}{10} = 9{,}9; R_{5.1} = \frac{9{,}9}{1800} = 0{,}005;\ T_{5.1} = \frac{2{,}6}{0{,}005^{1{,}1}} = \frac{2{,}6}{0{,}002} = 1300;$$

$$\overline{\tau_{5.1}} = \frac{1800}{1300} = 1{,}38.$$

The process of the information acquisition is formulated as follows:

$$\overline{I_{5.1}} = \left(\frac{1-e^{-1{,}38}}{1{,}38}\right) + \left(1 - \frac{1-e^{-1{,}38}}{1{,}38}\right) * 0{,}672 = 0{,}855$$

Let us compute the forgetfulness of the received information:

$$R^*_{5.1} = \frac{9{,}9}{172800} = 0{,}00005;\ T^*_{5.1} = \frac{2{,}6}{0{,}00001^{\,1{,}1}} = 260000;\ \overline{\tau_{5.1}}^* = \frac{172800}{260000} = 0{,}665;$$

$$\overline{I_{5.1}}^* = 0{,}61 + (0{,}855 - 0{,}61)e^{-0{,}665} = 0{,}736.$$

The calculations for the second part of the fifth task are as follows:

$$I_{\Sigma 5.2} = 3\,log_2 \frac{100}{10} = 9{,}9;\ R_{5.2} = \frac{9{,}9}{1800} = 0{,}005; T_{5.2} = \frac{2{,}6}{0{,}005^{1{,}1}} = \frac{2{,}6}{0{,}002} = 1300;$$

$$\overline{\tau_{5.2}} = \frac{1800}{1300} = 1{,}38.$$

The process of the information acquisition is calculated as follows:

$$\overline{I_{5.2}} = \left(\frac{1-e^{-1{,}38}}{1{,}38}\right) + \left(1 - \frac{1-e^{-1{,}38}}{1{,}38}\right) * 0{,}736 = 0{,}879.$$

Let us compute the forgetfulness of the received information as follows:

$$R^*_{5.2} = \frac{9{,}9}{172800} = 0{,}00005;\ T^*_{5.2} = \frac{2{,}6}{0{,}00001^{\,1{,}1}} = 260000;$$

$$\overline{\tau_{5.2}}^* = \frac{172800}{260000} = 0{,}664;\ \overline{I_{5.2}}^* = 0{,}63 + (0{,}879 - 0{,}63)e^{-0{,}664} = 0{,}767.$$

The computations for the third part of the fifth task are as follows:

$$I_{\Sigma 5.3} = 3\,log_2 \frac{100}{10} = 9{,}9;\ R_{5.3} = \frac{9{,}9}{900} = 0{,}01;\ T_{5.3} = \frac{2{,}6}{0{,}01^{1{,}1}} = \frac{2{,}6}{0{,}005} = 520;$$

$$\overline{\tau_{5.3}} = \frac{900}{520} = 1{,}7.$$

The process of the information acquisition is given by the following:

$$\overline{\mathrm{I}_{5.3}} = \left(\frac{1-\mathrm{e}^{-1{,}7}}{1{,}7}\right) + \left(1 - \frac{1-\mathrm{e}^{-1{,}7}}{1{,}7}\right) * 0{,}767 = 0{,}88.$$

The process of the information acquisition is illustrated schematically in Fig. 2.

Besides the results presented above, computations for different time intervals of presented information were made. They allow the authors to conclude that the task duration of 15 minutes is optimal and it is reasonable to increase the duration of the presented information a little in the last task or equally to decrease the amount of the information. It is possible to decrease the amount of the proposed information with the optimized routine for the instrument readings.

Thus, the weak growth of the information acquisition at the last stage of the training program proves that a necessary skills level in maintenance of attitude orientation is achieved.

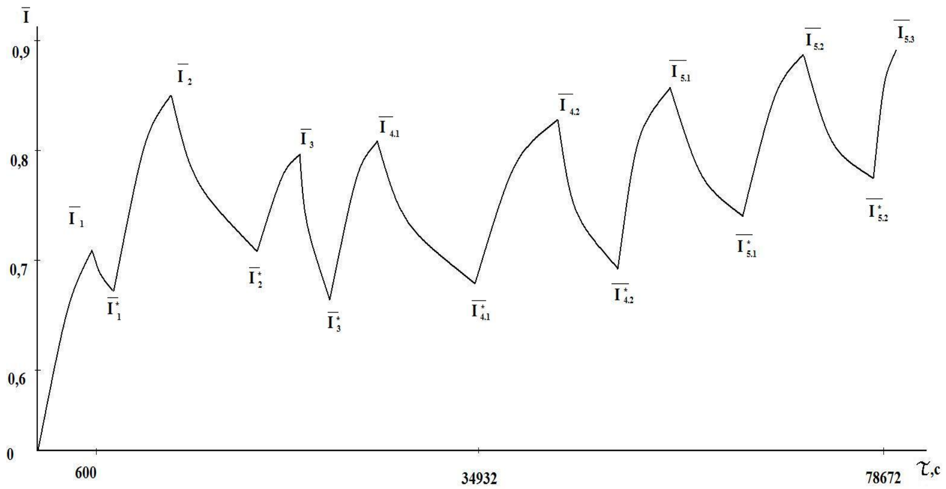


Fig. 2. The process of the information acquisition

The aim of the experiment is to collect the system estimates on the basis of which one can conclude that the proposed training method for maintenance of attitude orientation *inside-in* HI for the trainee-students is efficient.

Among the total number of students (76 persons), 61 experiment participants of the 3d course from the Faculty of Flight Operation of Civil Aircraft had been selected. Then with the help of a lottery method, 48 final participants were chosen. The students under the experiment were listed alphabetically, and with the help of the random numbers table [12, 13], they were divided into the experimental and control groups of 24 persons each.

The first stage of the experiment was a test, “Horizon indicator”, conducted for the experimental groups.

The aim of the test is to evaluate the equalization of skill levels of the experimental groups. In the test “Horizon indicator”, the participants of the experiment were provided with 50 images of *inside in* HI with rolls of different directions and roll rates (Fig. 3). The images were shown with the interval of three seconds. The students under the experiment had to determine the direction of the roll (left or right) and write down the answers in a special form.


Fig. 3. The typical images from the test “Horizon indicator”

The second stage of the experiment involved the procedural simulators.

The aim of the stage was to perform the tasks by an experimental group in order to acquire the piloting skills of an A/C with HI and to estimate their effectiveness. The second stage of the experiment is described in the article earlier.

The experimental group carried out the flights on the proposed program and the control group carried out the flights in circles (25 minutes), on route flights (2 hours) and the flight using flight instruments only (15 min). The total time of the training program in the simulators for every group made 2 hours and 40 min.

After the finishing of the program, two tests were performed on the procedural simulators. The tests were conducted only displaying the A/C instrument panel.

The aim of the first test was to verify the hypothesis that the experimental group carried out the piloting with HI more effectively and took less mistakable decisions while piloting an A/C with a roll.

The test included the following steps. The image of an instrument panel was hidden by a shield so that a student under the experiment could not see the image of the instrument panel and the movement of the control stick of a simulator. Then a roll in a horizon indicator was added, and after the operator's or his assistant's command "go out", the image of an instrument panel was shown and the student under the experiment made an A/C go out in level flight without a roll. Every participant of the experiment was given ten different rolls. The incorrect operations during rolling out of the aircraft (i.e. the rolling of an aircraft to increase the roll) were registered.

The second test was similar to the previous one but the pilot got an additional task. The drawbacks of the instruments (in our case, it is in adequate indication of a horizon indicator) are usually come out in complicated working conditions of a pilot causing lack of time, high workload and strong tension state [2].The loss of attitude orientation, as a rule, occurs in the state of a high psychophysical tension which was provoked by the additional task.

The aim of the second test was obtaining, as far as possible, the validity of the distinctions in the results of the control and experimental groups and also getting the additional information for the analysis of the training results.

The third stage of the experiment consisted of a complicated test, "Horizon indicator". It is aimed at getting additional information for the conclusions made previously in the second test. It was decided to extend the test "Horizon indicator" as the first test was not rather difficult for the students under the experiment. The test offered the students 50 images of the horizon indicator (*inside in*) with the rolls of different directions and rates. The complication of the test was achieved by turning the horizon indicator by the angle multiple 90 degrees (Fig. 4). The images were presented in intervals of three seconds. The students under the experiment had to determine the direction of the roll and write down the answer in the special form. In conclusion, the processing of the experiment results and their statistical analysis were made.

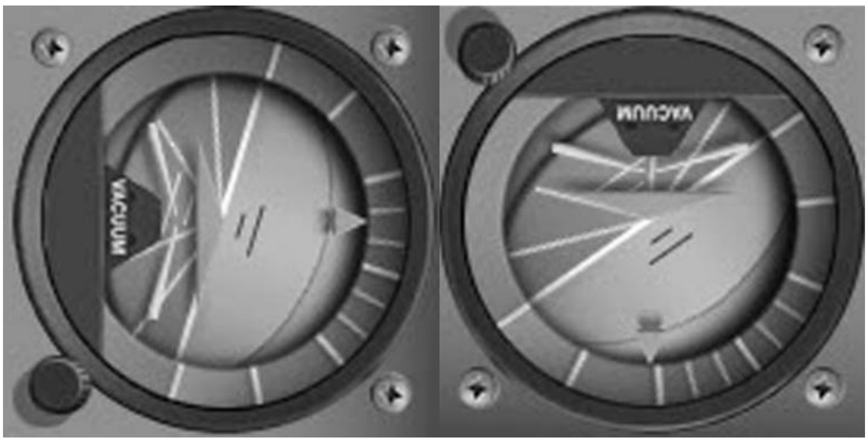


Fig. 4. The example of the image from the complicated test "Horizon indicator''

## 4. MATHEMATICAL PROCESSING OF THE EXPERIMENT RESULTS

### 4.1. The processing of the results of the test “Horizon indicator”

As a result of the test, the following data are received:

Table1

The results of the test “Horizon indicator”

| The number of mistakes | The number of persons who made mistakes | |
|---|---|---|
| | Control group | Experimental group |
| 0 | 20 | 18 |
| 1 | 2 | 3 |
| 2 | - | 2 |
| 4 | 1 | - |
| 13 | - | 1 |
| 28 | 1 | - |

By calculating almost all the estimates (average (M), mean-square deviation (σ), mean error of average (m), mean difference error (t), White’s test, Wilcoxon test, Spearman rank correlation and coefficient of correlation), a low probability of validity for the calculated values was obtained. Hence, one can conclude that the usage of the lottery method and the table of random numbers in general equalized the groups by their skill levels.

### 4.2. Processing of the test results with an additional task on a simulator

As the result of the test with an additional task on the simulator, the following data were received (Tab.2).

The computation of the numerical expressions in the second test was made the same way as in the first test.

Table 2

The number of mistakes in the test with an additional task on a simulator

| The number of mistakes | The number of persons who made mistakes | |
|---|---|---|
| | Control group | Experimental group |
| 0 | - | 6 |
| 1 | 4 | 12 |
| 2 | 10 | 4 |
| 3 | 1 | 2 |
| 4 | 4 | - |
| 5 | 4 | - |

Computing of the average (M)
Control group: $M_к = 2{,}73$
Experimental group: $M_э = 1{,}08$
Computing of the mean-square deviation (σ)
Control group: $\sigma_к = 1{,}42$
Experimental group: $\sigma_э = 0{,}88$
Computing of the mean error of average (m)
Control group: $m_к = \pm\frac{1{,}42}{\sqrt{23}} = 0{,}29$
Experimental group: $m_э = \pm\frac{0{,}88}{\sqrt{24}} = 0{,}18$
Computing of the mean difference error (t)

$$M_к - M_э = 1{,}65; 3\sqrt{0{,}084 + 0{,}032} = 1{,}02;$$

It should be noticed that the difference of the averages is more than three own mistakes:1,65> 1,02. Consequently, the computed numerical characteristics have statistically verifiable distinctions.

Let us compute t:

$$t = \frac{2{,}73 - 1{,}08}{\sqrt{0{,}084 + 0{,}032}} = 4{,}85\ ; C = 45$$

Then a verifiable distinction is determined by the table of probabilities on Student's distribution (P = 0,0001) [13]. The obtained result proves that the difference in the statistical results is truthful.

*White's test.* Coefficient T equals to 470 which is greater than the smallest sum of ranges

$T_э$= 398.Therefore, one can conclude that verifiable distinction between the cases is statistically valid.

*Wilcoxon test.* Let us compute the difference in the number of mistakes. We rank all the experimental values beginning with the smallest and finishing with the greatest value. At that one should take into consideration only the absolute values of difference, i.e. the greater is the difference the higher should be the rank.

Let us compute the sum of the ranks separately with negative and positive signs. Then, let us compute the sum of all the ranks. The total sum of all the ranges is 171. The sum with the negative signs is 9, and the sum with the positive signs is 162.

Let us determine a table criteria *z* for the significance level 0,05 and the number of comparable pairs (18) from the table "Values of Wilcoxon test" [13].

For 18 pairs under experimental observation, *z* equals 41. Let us compare the table criteria *z* with the smallest sum of ranks estimated above z = 41 > 9. Hence, there is statistically verifiable distinction between the two cases.

*Spearman rank correlation.* The computed correlation coefficient of ranks $\rho$ is

$$\rho = 1 - \frac{6*656}{20(20^2-1)} = 0{,}507.$$

Let us compare the obtained coefficient with the table value for 20 pairs. The significance level in the table [13] equals 0,377. Hence, the obtained correlation coefficient of ranks exceeds P = 0,05 and it can be considered significant with error probability less than 0,05.

*Correlation coefficient*. Let us put the obtained parameters into a formula:

$$r_{кэ} = \frac{12{,}8}{\sqrt{40{,}8*16}} = 0{,}501.$$

The obtained value of the coefficient of correlation is greater than the table coefficient [11,13], which equals 0,444. Hence, the correlation coefficient is significant.

Thus, one can conclude that the observed difference in the results of the control and experimental groups is statistically truthful.

### 4.3. Processing of the results of the complicated test ''Horizon indicator''

As the result of the complicated test ''Horizon indicator'' the following data are gained:

Table 3

The number of mistakes in the complicated test ”Horizon indicator”

| The number of mistakes | The number of persons who made mistakes | |
|---|---|---|
| | Control group | Experimental group |
| 0 | 6 | 12 |
| 1 | 4 | 2 |
| 2 | - | 4 |
| 3 | - | 1 |
| 4 | - | 1 |
| 5 | 2 | - |
| 6 | 2 | 1 |
| 7 | 2 | 1 |
| 8 | - | 1 |
| 9 | 2 | - |
| 10 | - | 1 |
| 16 | 1 | - |
| 18 | 1 | - |
| 19 | 1 | - |
| 22 | 1 | - |
| 25 | 1 | - |
| 32 | 1 | - |

The computation of the numerical expressions of the complicated test is the same as it is in the first one.
Computing of the average (M)
Control group: $M_к = 8$.
Experimental group: $M_э = 2$.
Computing of the mean-square deviation (σ)
Control group: $σ_к = 9{,}2$.
Experimental group: $σ_э = 2{,}9$.
Computing of the mean error of average (m)
Control group: $m_к = \pm \frac{9{,}2}{\sqrt{24}} = 1{,}88$.
Experimental group: $m_э = \pm \frac{2{,}9}{\sqrt{24}} = 0{,}59$.
Computing of the mean difference error (t):

$$M_к - M_э = 6; 3\sqrt{3{,}53 + 0{,}35} = 5{,}9;$$

The difference of the averages is more than three own mistakes: 6 > 5,9. Hence, the computed numerical characteristics have statistically verifiable differences.

Let us compute t: $t = \frac{8-2}{\sqrt{3{,}53+0{,}35}} = 3$ ;C = 46

Then a verifiable distinction is determined by the table of probabilities on Student’s distribution P = 0,0027 [13]. The obtained result proves that the difference in the statistical results is truthful.

*White’s test*. Let us compute the sums of ranks $T_к$ and $T_э$ of the control and experimental groups for the series $R_к$ and $R_э$. We get $T_к = 702$, $T_э = 474$.

Let us compare the smallest sum of the ranks $T_э= 474$ with the table coefficient T from the table ”Values of White's test” [7]. The coefficient T equals 508 which is greater than the least sum of the ranges $T_э= 474$. Therefore, one can conclude that there is a statistically valid difference between the cases.

*Wilcoxon test.* Let us compute the sum of the ranks separately with negative and positive signs. Then, let us compute the sum of all the ranks. The total sum of all the ranks is 136; the sum with the negative signs is 7; the sum with the positive signs is 129.

Let us determine the table criteria *z* for the significance level 0,05 and the number of comparable pairs (16) from the table “Values of Wilcoxon test” [11,13].

For 16 pairs under experimental observation *z* equals 31. Let us compare the table criteria *z* with the least sum of the ranks z = 31 > 7. Hence, there is statistically verifiable distinction between the two cases.

*Spearman rank correlation*. The computed correlation coefficient of ranks ρ is

$$\rho = 1 - \frac{6*496{,}5}{20(20^2-1)} = 0{,}627.$$

Let us compare the obtained coefficient with the table value for 20 pairs. The significance level in the table [11] equals 0,377. Hence, the obtained correlation coefficient of ranks exceeds P = 0,05 and P = 0,01, and can be considered significant with error probability less than 0,01.

*Correlation coefficient*. Let us put the obtained parameters in a formula:

$$r_{кэ} = \frac{257{,}32}{\sqrt{1030*142{,}4}} = 0{,}672.$$

It is well known that if the pair factors are less than 100, then it is reasonable to estimate validity using the table of critical values for the correlation coefficient $r_{кэ}$. The obtained value of the correlation coefficient is more than the table coefficient [11] which equals 0,444. Hence, the correlation coefficient is significant.

According to the results of the complicated test ”Horizon indicator”, one can conclude that the obtained difference from the results of the control and experimental groups is statistically truthful.

## 5. RESULTS DISCUSSION

The results of the test ”Horizon indicator” allow us to confirm that the usage of the lottery method and the table of random numbers in general equaled skill levels of the control and experimental groups.

During the calculation of the error difference and White's test in the experiment on the simulator, a low probability of the calculated data validity was observed. It proves that the difference between the number of mistakes in the control and experimental groups during the testing on a simulator does not reveal high validity.

In the test with the additional task, statistically valid results of all criteria have been proved. Therefore, one can conclude that in this test the difference in the number of mistakes in the control and experimental groups has a high probability of validity.

The difference in the control and experiment groups in the complicated test “Horizon indicator” is statistically truthful. It is known that the main mental effort, which the pilot makes in the process of the formation of A/C attitude orientation image, is the visual rotation of the image elements which was reproduced in this test. Thus, one can confirm that the skill level for maintaining of attitude orientation increased. The probability of unmistakable trainee-students operation in the control and experimental groups was measured as 0,726 and 0,892, respectively. The finding confirms the reliability increasing in attitude orientation during the *inside-in* HI flight.

## 6. CONCLUSIONS

The processing of the experimental data shows that the probability of unmistakable trainee-students operation increased up to 0,892. Hence, one can conclude that the reliability in attitude orientation during the *inside in* HI flight increased.

The processing of experimental data for the complicated test “Horizon indicator” allows us to confirm that the skill in maintaining of attitude orientation improved.

Consequently, one can also confirm that the training method on maintaining of attitude orientation proposed by the authors allows one to increase the reliability of the A/C piloting using the *inside-in* HI under difficult flying conditions.

The proposed mathematical model is in good agreement with the results of the experiment held at the Chair of Flight Operations and Professional Training of Aviation Personnel at St. Petersburg Sate University of Civil Aviation.

The proposed training method was also patented [14].

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