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Research Article

POSSIBLE SOLUTIONS TO REDUCE THE NEGATIVE IMPACT OF HUMAN FACTORS ON FLIGHT SAFETY

SMUROV M.Y.*, ARINICHEVA O.V., KOVALENKO G.V., BALYASNIKOV V.V. AND CHEPIGA V.E.

St. Petersburg State University of Civil Aviation, 196210, St. Petersburg, Pilotov str., 38, Russia

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ABSTRACT

The article studies the questions of assessing the effectiveness of interaction in a pair of pilots. For the experiment, specific computer programs were used: "Stealth", "Homeostat", "Viper", "Chkalovsky-2", "Azeff", "CrossCheck 1", "CrossCheck 2", and "Ring-2". The socionic model of intertype relations was proposed by Gulenko. All these programs are contained in the application package (AP). The authors describe the approaches, by which the negative impact of human factors on safety can be reduced.

The statistical experiment results are given, as well as the calculated correlations of obtained parameters including color sociometry data and the style of behavior. The conclusions are drawn about the effectiveness and the possibility of further development of the AP. In conclusion, the prospects of further activities are described, as well as the possible difficulties that may arise in the implementation of new training systems.

INTRODUCTION

It is well known (Leichenko, *et al*., 2006a) that 80% of all flight accidents (FA) in Russia and around the world come for reasons related to the human factor (HF). Therefore, finding ways to reduce the negative impact of the HF on the flight security (FS) is an important and urgent problem.

METHODS

The According to the authors, to date, there are several ways to solve this problem.

The first way is special training programs on interaction among the aircraft crew (AC), the first and foremost is the program "Cockpit/Crew Resource Management" (CRM) (Leichenko, *et al*., 2006b; Mikhailik, *et al*., 1999); these programs became the first ways to reduce the negative impact of human factors on FS.

A resonance air disaster, which served as the impetus for this way, became a disaster of the United Airlines DC-8-61 Airline in the area of Portland (USA), killing 10 of the 189 people on board. As a result of the investigation, the commander was named responsible for the disaster, who did not pay attention to the comments of other crew members to a low level of fuel. At the same time, the disaster highlighted the need to change work within the flight crew, resulting in a wide response. As a result, special programs and techniques were introduced, which radically changed the job of flight crews. At the moment, this way is the "mainstream" in the world. Far from denying the importance of the way, it should be noted that it is not the only possible way.

The second way is the further improvement of the existing professional and psychological selection (PPS) of pilots. In particular, the fundamental papers in this field (Malishevskiy, *et al*., 2011; Malishevskiy, *et al*., 2005; Malishevskiy, *et al*., 2009; Malishevskiy, 2010; Dzhafarzade and Malishevskiy, 2013) were devoted to this problem of the disadvantages of the existing PPS and possible ways of its improvement.

***Corresponding authors email: info@spbguga.ru**

These two ways to reduce the negative impact of the HF on the FS are well recognized and do not require further explanation.

The third way is a way of a pilot's individual extreme performance improvement (Mikhailik, *et al.*, 1999; Mikhailik and Malishevskiy, 1999; Leichenko, *et al.*, 2006; Mikhailik, *et al.*, 1999; Grigor'ev, *et al.*, 2006; Paşayev, *et al.*, 2005). This way is not widespread now, although it was embedded as an element of CRM Russia Program (Leichenko, *et al.*, 2006a; Mikhailik, *et al.*, 1999; Mikhailik and Malishevskiy, 1999).

However, in our opinion, neither the PPS nor the training programs on interaction cannot completely solve the problem of reducing the negative impact of the HF on the FS, although in Western countries, the CRM training is conducted since the early 1980s (in the United States from 1979 (Leichenko, *et al.*, 2006), in Russia from 1990 (although it became widespread only in 2003 (Leichenko, *et al.*, 2006). Nevertheless, a very typical example is a disaster of the aircraft Beechcraft King Air A100 on January 7, 2007 in Saskatchewan. According to the FA Investigation Commission, the crew was unable to work effectively as a team to avoid the FA, or mitigate errors and safely manage the risks associated with the flight because the crew did not interact with each other, in particular because the pilots did not get training in the area of the CRM programs. Also, on May 22, 2010 in Mangalore, Boeing 737 of AirIndia en route from Dubai to Mangalore skidded off the runway during landing and burst into flames. There were 160 passengers and 6 crew members on board. Only 8 people were found alive, but one of them died on the way to the hospital. During the FA, the co-pilot repeatedly recommended to the commander to go to the second round, but the attempt to do so was made after the start of the aircraft run on the runaway. Another example is a disaster of Tu-154 of Dagestan Airlines on December 4, 2010 in Domodedovo Airport. One of the reasons was that the commander did not make instructions and delegate responsibilities in the crew, as well as independent, not always correct actions of the crew members, and insufficient preparation of the commander in crew resource management (CRM). And these are just a few of similar examples: Taiwan, Donetsk, Petrozavodsk, Yaroslavl, the list goes on.

The author believes that it is worth paying attention to another way of solving the problem of reducing the negative impact of the HF on the FS. This fourth way is very well seen on the example of a disaster of the Aeroflot-North Boeing 737-505 which occurred on September 13, 2008 in Perm region.

If we carefully read "Accident Investigation Final Report" by the Commission on Aircraft Accident Investigation of Interstate Aviation Committee, it says that "the acquisition of the crew was carried out without taking into account the level of professional training of the AC commander and co-pilot. The AC commander, who had a little experience in this position, was attached a co-pilot in the two-member crew, who had a little experience in this type of aircraft, both previously performed flights only in a multi-member crew. According to independent psychologists, at manning the psychological characteristics of individual pilots were also not taken into account. That is, there are people who are very difficult and sometimes even impossible to communicate effectively with each other. And the interaction training programs cannot completely fix the situation (Malishevskiy, *et al.*, 2014). The authors believe that it is necessary to develop techniques in order to not gather unsuitable people in one crew.

This problem is very complex and often considered, in particular, in (Mikhailik and Malishevskiy, 1999; Leichenko, *et al.*, 2006b; Malishevskiy, *et al.*, 2014; Mukhtarov, *et al.*, 1999; Leichenko, *et al.*, 2002; Malishevskiy and Arinicheva, 2008; Malishevskiy and Arinicheva, 2008; Malishevskiy and Parfenov, 2010; Malishevskiy and Brovkin, 2014) and other papers. The process of finding a criterion for evaluating the pilots' interaction effectiveness is the most difficult. This article is devoted to this important and urgent issue.

The authors together with Maliszewski, teacher of Department 21 Flight Operation and Training of Aviation Personnel, developed the application package (AP) for pilot training under the education program "CRM – Two-Member Crew Management", advanced training courses for flight crew of civil aircraft and initial training on the subject of "CRM – Crew Resource Management" for civil aircraft crew members. The software package was introduced in the educational process of the department and the Flight Training Center of the Aviation Educational Center of St. Petersburg State University of Civil Aviation (Vlasov, 2012).

This package consists of eight applications (Table 1). Their objectives include interaction training methods between the crew and the evaluation of its effectiveness. The software varies by the methods of interaction and complexity. The easiest, warm-up program Ring-2 (Vlasov, 2012) is developed for testing the motor interaction in the pair and monitoring its effectiveness. Use the control buttons you need in the shortest possible time to lead a co-controlled object (a red dot) on the playing ring field. The first player controls the movement of the dot on the vertical axis, while the other player controls the movement horizontally. Being equidistant from the circumferences bounding the playing field, the dot has a maximum speed, which decreases linearly as it approaches the boundary of the field. A measure of evaluating the interaction effectiveness is the time, for which the players complete one turn clockwise. Because of the low information load, the scatter of results is not large, and therefore, this application is suitable exclusively for the warm-up (Vlasov, 2012).

Chkalovsky-2 is a warm-up task in order to work out the motor interaction in the pair and monitoring its effectiveness (Malishevskiy and Brovkin, 2014). Using the control keys, the left and right participants should in the shortest possible time hold a red plane shadow figure on one of the selected routes #1 or #2. After entering all the necessary input data and pressing Start, the GUI becomes the source view; when pressing OK button, the timer switches on at the top center of the GUI and exercise control keys are unlocked. After the start of the exercise and to the end, the red plane shadow figure shows its actual location, and the timer shows the time from the start of exercise. The exercise ends after the completion of the route, the corresponding information appears. Next, after pressing OK, you can either make one more attempt by activating the sub-menu option New Game in the menu Game, or shut down by activating the sub-menu option Exit.

One more exercise Viper (Malishevskiy, *et al.*, 2014) is developed for testing the motor interaction in the pair and monitoring its effectiveness. The main exercise menu has Info and Help sub-menus. The Info sub-menu contains options Result and Exit. The Help sub-menu has options Settings, Help and About. The algorithm of the software operation possesses a number of characteristics that affect the dynamic properties of the object, that is a dot. By activating Settings option, a window "Dynamic Object Properties" is displayed on the screen, as well as a dialog box "Evaluation Criteria". Using the control keys, two subjects should in the shortest time lead the red dot from start to finish on the complex closed route. Tap the side boundaries of the route is penalized by temporary loss of control, the dot is repainted from red to blue. To control, the subjects are provided two keys. One participant controls the dot in the horizontal plane, and the other participant controls it in the vertical plane. At the top of the exercise GUI, the current parameters of the dot velocity in the horizontal and vertical planes are displayed including the maximum velocity reached during the game through the inclined line. There is also information in the form of a time counter. There are three keys at the bottom of the exercise GUI: Training, Start, Exam. The Training mode is designed to familiarize the participants with the process of the exercise. Exam is the main mode. Start button allows you to start the exercise in the selected mode and start the countdown. The exercise ends after the completion of the route, the corresponding information appears. At the end of the route, a window "Results" is displayed automatically with the current results and previous results.

A more complex exercise on motor interaction is the exercise "Azeff" (Vlasov, 2012) (Table 1). Its objectives include development of anticipation. The exercise task is to hold a strip within the permissible values. The direction and speed of the strip is resultant of the control actions by two players, as well as a periodically varying factor to destabilize the strip position. Depending on the mode of application, the players are additionally limited in time. During the exercise, time is counted for the strip held within predetermined limits (T), time for the strip held beyond predetermined limits (T_D), as well as the maximum (D_{max}) and average (D) deviations of the strip from the zero. The most informative value used to evaluate the effectiveness is T, T_D is less informative and used as an auxiliary evaluation factor. The values D_{max} and D are not important in practice.

The exercise "CrossCheck 1" is a task for developing cognitive and motor interaction in the pair in cross-mode control and evaluating its effectiveness (Vlasov, 2012) (Table 1). The game situation is the emergence of a circle of random color (from a specific set of possible colors) on the left edge of the playing field and its movement at a given speed to the right edge of the field. Two players have to react to emerging game situations, repeatedly pressing the keys indicated at the tips on the right of the playing field. Each player can press the keys of the sets individually determined for each player. A successful reaction of the players is considered to be the appropriate action before the circle reaches the right edge of the playing field. In Read-And-Do mode, the occurrence of circles of random colors is added to above mentioned game situations (from a specific set of possible colors) at any point of the operating system desktop. The reaction time is limited to the number indicated in the circle center; and the keys are indicated in the tip given to the players in printed form. In both modes, a mistake is any invalid keystroke or lack of response in the required time. The number of mistakes made by players is the criterion of evaluation of the interaction effectiveness.

The application "CrossCheck 2" pursues the same objectives as the "CrossCheck 1", but in this exercise, the players are strictly separated and have nothing common to do before the special game situations that require joint action of both players. In normal mode, the first player has to react in a certain way to emerging figures by pressing certain keys. While the second player uses the control keys to hold two periodically changing values at the minimum possible deviation from the initial position (Malishevskiy, *et al.*, 2013; Vlasov, 2012). If there is a special game situation, the players are required to press certain keys in a certain sequence for each type of special situation (total, there are three types). The interaction effectiveness is determined individually for each player based on the efficiency of his or her actions in the normal mode, taking into account the mistakes made in special situations.

The Stealth task is intended for practicing cognitive interaction in the pair and monitoring its efficiency (Leichenko, *et al.*, 2006b; Vlasov, 2012). The task has primarily a training character and is suitable for all categories of aviation personnel. The task of the trainees is to land the aircraft in a simulation of management failures as defined in an algorithm by a certain teacher. Depending on the operating mode, the trainees are required additional constraints, such as landing time, a number of landings. Monitoring the interaction effectiveness is hindered because of the excessively rough handling scale and difficulty in its standardization.

The exercise "Homeostat" is intended for the implementation of cognitive and motor variant of interaction (Malishevskiy, *et al.*, 2006). Generally, a homeostat is an analog electromechanical device that simulates the properties of living organisms to maintain some of their characteristics (such as body temperature, blood oxygen content) within an acceptable range. With regard to psychological research, the homeostat is a special mechanical device, in which with the help of knobs moving an object on one of the coordinate axes, it is necessary to hold the object on a certain trajectory by the joint efforts of people, where each person rotates an individual knob. Obviously, it is impossible without a high coherence of effort. The Homeostat playing field contains a schematic representation of the runway, which is drawn on top of the main dialogue box of the game, and the so-called landing system coverage localizer zone denoted by two white rays emanating from the left and right edges of the runway. The application simulates the landing; and the task of players is through concerted action to achieve the integrity in the team and to land the aircraft. If at any time the aircraft shadow figure goes beyond the localizer zone, it means a missed approach. The application contains two basic modes "Training" and "Exam". In Training mode, data logging is disabled, and you can make a few training attempts for the acquisition of the necessary primary skills. There is indication of the misinteraction value of the participants. In turn, Exam mode requires stable management skills acquired in Training mode in order to achieve the main goal that is error-free landing of the virtual aircraft shadow figure on the virtual runaway, which in general is the result of concerted actions of the players, but in real life it is landing of the real aircraft on the real runaway with the help of concerted actions of the crew. In this mode, the record is continuously carried out for the basic physical parameters of the player-controlled model, namely, an every-second record is input in the flight logfile (in seconds), remove to the runway (in meters), the linear lateral deviation (LLD) (in meters), magnetic heading (in degrees), the AC roll-off, the so-called total resultant roll-off (in degrees), the participants' interaction in roll-off on the left and right (in degrees), and the last parameter that is the current interval of the misinteraction in the roll-off by two players (in degrees). According to these parameters, you can later restore the flight and judge the actions of the right and left players in controversial situations. As already mentioned, the application simulates landing, and wherein the roll control of the aircraft can be carried out only by the synchronized actions. In case if asynchronous behavior is greater that given, the aircraft roll-off remains unchanged in the last saved position. Typically, a leader is detected in each of the pairs who directs the actions of the participants, consisting of developing a strategy for solving the task, and navigational synchronous control actions. Thus, this task is implementing the cognitive and motor interaction option.

RESULTS

All software products listed in Table 1 were used to varying degrees in experiments with the pilots in 2003-2014. In order to somehow compare disparate results on the basis of a few exercises, the mean total interaction effectiveness scale was deduced (ℵΣ), which, of course, is not quite correct, and only suitable for very approximate estimations. Experimental conditions are also different, which left its negative impact on the final result. Integral assessment ℵΣ correlates with other effectiveness criteria very insufficiently and often not in accordance with theoretical predictions, as can be seen in Table 2 (Malishevskiy, *et al*., 2014).

As the effectiveness criteria, Table 2 also uses a sum (Σ_S) and the difference (Δ_S) of vector modules defining the personal style of human behavior on the grid μ_2 (Leichenko, *et al*., 2006a), and the distance between two points that determine the personal style of the behavior on the grid μ_2 (R_S) (Malishevskiy, *et al*., 2014). These values are determined by the formulas (Malishevskiy, *et al*., 2014):

$$\Sigma_S = \left|\overline{r_1}\right| + \left|\overline{r_2}\right|$$

$$\sum s = \left|\overline{r_2}\right| + \left|\overline{r_2}\right|$$

$$\Delta_S = \left\|\overline{r_1}\right| - \left|\overline{r_2}\right\|$$

$$R_s\sqrt{\left(C_1 - C_2\right)^2 + \left(L_1 - L_2\right)^2 + \left(P_1 - P_2\right)^2}$$

C_i, L_i, P_i are μ_2 grid coordinates defining the i-th style of behavior (Leichenko, *et al*., 2006a);

$\left|\overline{r_1}\right| = \sqrt{C_i^{\,2} + \left(L_i - 50\right)^2 + \left(P_i - 50\right)^2}$ – a vector module on μ_2 grid defining the i-th style of behavior $\left(i = \overline{1,2}\right)$ (Leichenko, *et al*., 2006a).

Another criterion of effectiveness used in Table 2 is a prognostic socionical effectiveness criterion (PSEC). Its various versions are investigated in papers (Leichenko, *et al*., 2006a; Malishevskiy, *et al*., 2014; Malishevskiy and Arinicheva, 2008; Malishevskiy and Parfenov, 2010; Malishevskiy and Brovkin, 2014; Malishevskiy, *et al*.,2013; Malishevskiy and Brovkin, 2014; Arinicheva, *et al*., 2008). In this case, we used the PSEC, which was also previously used in papers (Malishevskiy, *et al*., 2014; Malishevskiy, *et al*., 2013):

ℵ04 = ℵ(+) - ℵ(-)

Where $\aleph_{(+)} = (6\Omega_1 + 6\Omega_3 + 6\Omega_5 + 6\Omega_7 + 3\Omega_9 + 3\Omega_{11} + 3\Omega_{13} + 3\Omega_{15}) / 8$;

$\aleph_{(-)} = (6\Omega_{16} + 6\Omega_{14} + 6\Omega_{12} + 6\Omega_{10} + 3\Omega_8 + 3\Omega_6 + 3\Omega_4 + 3\Omega_2) / 8$;

Ω_i – the i-th component of the PSEC, which is calculated for intertype relations (IR) according to Gulenko (Leichenko, *et al*., 2006a; Malishevskiy, *et al*., 2013).

The PSEC is determined using the MM-1 Test (the 5th edition) (Arinicheva and Malishevskiy, 2010; Arinicheva and Malishevskiy, 2014), and the sum (Σ_S) and the difference (Δ_S) of vector modules defining the personal style of human behavior on the grid μ_2 (Leichenko, *et al*., 2006a), and the distance between two points that determine the personal style of the behavior on the grid μ_2 (R_S) (Malishevskiy, *et al*., 2014 are calculated using MMY-1 Test (Malishevskiy, *et al*., 2014; Arinicheva and Malishevskiy, 2010).

Finally, normativity (N), the valency (V) and the total scale (Σ_{NV}) are determined using the relationship color test (RCT) according to Etkind (Etkind, 1980).

DISCUSSION

In using of the AP and studies (Malishevskiy, *et al*., 2014; Malishevskiy and Arinicheva, 2008; Malishevskiy and Arinicheva, 2008; Malishevskiy and Parfenov, 2010; Malishevskiy and Brovkin, 2014; Vlasov, 2012; Malishevskiy, *et al*., 2006) conducted on the basis of statistics collected, several problems have

Table 1. Software used in experiments to determine interaction effectiveness with special software (Malishevskiy, Brovkin, & Vlasov, 2014)

	Software	Developers	Interaction Mode	Link to Description
1	Ring-2	A.V. Maliszewski, E.V. Vlasov	Motor	(Vlasov 2012)
2	Azeff	A.V. Maliszewski, E.V. Vlasov	Motor	(Vlasov 2012)
3	Chkalovsky-2	A.V. Maliszewski, P.E. Brovkin	Motor	(Malishevskiy, & Brovkin, 2014).
4	Viper	A.V. Maliszewski, P.E. Brovkin	Motor	(Malishevskiy, Brovkin, & Vlasov, 2014)
5	Stealth (2nd Ed.)	N. F. Michaylick, A.V. Maliszewski, E.V. Vlasov	Cognitive	(Leichenko, Malishevskiy, & Mikhailik, 2006a; Vlasov 2012)
6	Homeostat	A.V. Maliszewski, I.A. Parfenov	Cognitive & Motor	Malishevskiy, Arinicheva, Parfenov, & Petrova, 2006)
7	CrossCheck 1	A.V. Maliszewski, E.V. Vlasov	Cognitive & Motor	(Vlasov 2012)
8	CrossCheck 2	A.V. Maliszewski, E.V. Vlasov	Cognitive & Motor	(Malishevskiy, Arinicheva, & Brovkin, 2013; Vlasov 2012)

Table 2. Correlations between indicators identified $\aleph 04$, N, V, ΣNV, ΣS, ΔS, RS and $\aleph\Sigma$ when examining 61 pairs of the experiment participants (professional pilots and students) (Malishevskiy, Brovkin, & Vlasov, 2014)

Effectiveness Indicators	$\aleph_{04}$	N	V	Σ_{NV}	$\aleph_{\Sigma}$	Σ_S	Δ_S	R_S
$\aleph_{04}$	--	-0.0961	+0.2217	+0.0825	-0.0394	+0.0044	+0.1102	-0.2532
N	$P \le 0.95$	--	+0.1971	+0.7705	+0.0400	+0.2747	+0.2444	+0.1754
V	$P \le 0.95$	$P \le 0.95$	--	+0.7768	+0.0303	+0.0910	+0.3170	-0.0429
Σ_{NV}	$P \le 0.95$	P>0.999	P>0.999	--	+0.0454	+0.2356	+0.3631	+0.0848
$\aleph_{\Sigma}$	$P \le 0.95$	$P \le 0.95$	$P \le 0.95$	$P \le 0.95$	--	+0.1119	+0.2121	-0.0235
Σ_S	$P \le 0.95$	P>0.95	$P \le 0.95$	$P \le 0.95$	$P \le 0.95$	--	+0.2820	+0.2086
Δ_S	$P \le 0.95$	$P \le 0.95$	P>0.95	P>0.99	$P \le 0.95$	P>0.95	--	+0.4288
R_S	P>0.95	$P \le 0.95$	$P \le 0.95$	$P \le 0.95$	$P \le 0.95$	$P \le 0.95$	P>0.999	--

Note: There are values of the Pearson correlation coefficient (Arinicheva, & Malishevskiy, 2010) on the right top between the effectiveness indicators; the correlation significance characteristics (Arinicheva, & Malishevskiy, 2010) are in the left bottom.

been identified, the solution of which is the main direction of further activities. The lack of statistical data and a weak correlation of results are significant obstacles to the establishment and improvement of training and professional psychological selection methods of aviation personnel. Therefore, building the statistics and the use of multivariate statistical analysis are a priority for the near future, since in some cases the reasons for the weak correlations are quite obvious and related to the influence of unaccounted factors.

CONCLUSION

With the growing amount of data, filtering the random mistakes that inevitably arise during the exercises has become an urgent problem. In addition to the extensive measures requiring minor changes to existing facilities, it is necessary to make methodological revision requiring major modifications of the AP provided.

A promising way forward is to create the applications with the use of modern computer graphics, allowing the use of familiar images for the trainees (images of real aircraft instruments, panels and controls). For older age groups, there are problems associated with the use of a personal computer, so with the excellent response and sufficient coherence, there are insufficient motor skills of using the I/O devices that negatively affects the time and result of the exercise performance. At the same time, for the younger generation, this problem is almost not relevant; therefore, there is an additional correlation of the experimental results and the age of the subjects. Despite the deficiencies found, a positive effect of the described AP introduction includes improvement of the quality and efficiency of CRM flight crew training (the first way to reduce the negative impact of the human factors on the flight safety); the use of this application package will eventually allow us to find a prognostic interaction effectiveness criteria in order to solve the problem of the proper aircraft crew acquisition (the fourth way to reduce the negative impact of the human factor on the flight safety).

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