UDC 613.693
DOI: 10.21668/health.risk/2022.2.07.eng

Read online

Research article

DEVELOPMENT OF A NEW CONCEPT FOR ASSESSING WORK INTENSITY OF CIVIL AVIATION PILOTS

E.V. Zibarev[1], I.V. Bukhtiyarov[1], O.K. Kravchenko[1], P.A. Astanin[2]

[1]Izmerov Research Institute of Occupational Health, 31 Budennogo Ave., Moscow, 105275, Russian Federation
[2]Pirogov Russian National Research Medical University, 1 Ostrovityanova Str., Moscow, 117321, Russian Federation

The article describes a concept for assessing work intensity (WI) developed by the authors. This concept is based on the results produced by comprehensive assessment of the current working conditions, by analyzing the psychophysiological state of civil aviation (CI) pilots in flight, as well as by assessing a contribution made by flight loads and signs of fatigue to an increase in a risk of aviation accidents (AA).

It has been established that, according to sanitary and hygienic profiles, WI levels at all workplaces of civil aviation pilots correspond to harmful working conditions, which are aggravated by exposure to four other harmful factors (noise, microclimate, vibration, and working posture) in 48 % of cases.

The research results have shown that the risks of fatigue increase significantly after 5 hours of flight. This fatigue manifests itself in the growing number of gaze fixations by 11 %; an increase in an average latency period of a complex visual-motor reaction, by 12 %; the growing number of significant errors for flight safety, by 50 %. All these processes occur in the absence of physiological recovery of the cardiovascular system, $p < 0.05$. Pilots who are in a state of fatigue and stress due to violated work and rest regimes tend to have more AA. This accounts for at least 8.4 % of cases from all others causes.

It is proposed to introduce the 3rd degree of harmfulness for strenuous work, as well as new WI indicators for sensory, informational and intellectual loads, such as an increase in a time required to fix the gaze on a device (in %), the frequency of image / value change on a screen (times/min), the volume of information flows per unit of time (bps), and the number of multifunctional devices (more than 10 bits per second). It has been established that the assessment of WI should be supplemented with specific indicators of the flight load and work regimes. These indicators include the number of takeoffs and landings, the number of crossed time zones, the number of stress factors during a flight, and the number of night flight shifts per week. They are directly related to developing fatigue among pilots and an increased risk of AA occurrence.

Keywords: *work intensity, information loads, flight simulators, eye-tracking, fatigue, flight safety, risks of aviation accidents, psychophysiological studies, questioning.*

Work intensity (hereinafter WI) is among the most complicated indicators that describe working conditions. It is very difficult to formalize and regulate quantitatively. The first criteria to assess WI were mentioned about 30 years ago in the Guide R 2.2.013-94 “Hygienic criteria for assessing working conditions as per adverse and hazardous occupational factors, work hardness and intensity”[1] and this was a theoretical breakthrough in occupational medicine. However, these criteria have never been revised since then whereas work process has undergone substantial changes. It has become more productive, intellectual and intensive due to information technologies being implemented into it. These processes make control over WI even harder, especially when it comes down to performing highly intellectual work tasks. It con-

---

Evgeny V. Zibarev – Candidate of Medical Sciences, Deputy Director for Research (e-mail: zibarevevgeny@gmail.com; tel.: +7 (921) 953-02-73; ORCID: https://orcid.org/0000-0002-5983-3547).

Igor V. Bukhtiyarov – Academician of the Russian Academy of Sciences, Doctor of Medical Sciences, Professor, director (e-mail: info@irioh.ru; tel.: +7 (495) 365-02-09; ORCID: https://orcid.org/0000-0002-8317-2718).

Olga K. Kravchenko – Candidate of Medical Sciences, Leading Researcher (e-mail: kravchenko_ok@inbox.ru; tel.: +7 (915) 214-91-25; ORCID: https://orcid.org/0000-0001-6509-2485).

Pavel A. Astanin – assistant at Medical Cybernetics and Informatics Department (e-mail: med_cyber@mail.ru; tel.: +7 (983) 158-08-14; ORCID: http://orcid.org/0000-0002-1854-8686).

[1] R 2.2.013-94. Hygienic Criteria for Evaluation of Labour Conditions by Indexes of Harmfulness and Danger of Industrial Environment and Working Process Difficulty and Intensity (approved by the first deputy to the Head of the RF State Sanitary Epidemiologic Surveillance Service and deputy to the RF Chief Sanitary Inspector on July 12, 1994). *KODEKS: electronic fund for legal and reference documentation.* Available at: https://docs.cntd.ru/document/1200003682 (March 11, 2022) (in Russian).

cerns not only methodical support but also available assessment criteria being insufficient and limited by too narrow boundaries.

Work performed by pilots who fly modern aircrafts (AC) belongs to the most intensive ones. On one hand, the most sophisticated achievements in avionics are now implemented in civil aviation and it makes AC piloting simpler and easier. On the other hand, this means that pilots are required to mobilize all the functions of their analyzers in order to provide maximum possible concentration, attention focus, prompt decision-making and fast reactions when dealing with constantly changing information.

Assessment of WI for pilots is complicated further due to specific occupational factors at their workplaces. These factors create a whole lot of peculiarities typical for flying including high responsibility; a great number of incoming signals; frequent necessity to make decisions given critical time deficiency; working in shifts with different durations of a shift combined with substantial physiological costs; alternation between day and night shifts; necessity to cross several time zones; developing desynchronosis; possible spatial disorientation and delusions during a flight[2].

The analysis of regulatory and legal documents has revealed the existing gaps in the system for regulation of working conditions for aircraft crewmembers employed in civil aviation. This system is limited to assessing only three occupational factors (noise, microclimate, and lighting). Still, according to some hygienic standards[3], four classical WI indicators are listed among psychophysiological factors (three of them concern sensory loads and the remaining one is about work monotony). However, even this limited list of WI indicators is not sufficient to assess flight burdens on a pilot objectively. We should state that at present noise levels tend to be lower in cabins of up-to-date AC and WI is becoming a leading factor that determines working conditions [1, 2]. It is important to control WI since there is a substantial probability of developing fatigue among pilots, a growing number of errors in their work and, as a result, an elevated risk of aviation accidents.

However, approaches to measuring and assessing WI that are stipulated in basic regulatory documents[4] have certain limitations in their use for this occupational group. To be exact, they do not give an opportunity to assess WI at pilots' workplaces considering multiple action algorithms at different stages in a flight; they have inherent subjectivity of assessment as per specific indicators; they do not involve using up-to-date measuring equipment; they do not regulate conditions for accomplishing relevant measurements (a real flight or a simulator).

---

[2] Sanitarno-gigienicheskaya kharakteristika vrednosti, opasnosti, napryazhennosti, tyazhesti truda chlenov ekipazhei vozdushnykh sudov grazhdanskoi aviatsii Rossii: rukovodyashchii dokument (utv. Glavnym gosudarstvennym sanitarnym vrachom RF i Federal'noi aviatsionnyi sluzhboi RF 13, 14 oktyabrya 1997 g.) [The sanitary-hygienic profile of harmfulness, hazard, intensity and hardness of work performed by aircraft crewmembers in Russian civil aviation: the guide (approved by the RF Chief Sanitary Inspector and the RF Federal Aviation Service on October 13, 14, 1997)]. *GARANT: information and legal support*. Available at: https://base.garant.ru/71554050/ (March 12, 2022) (in Russian).

[3] SanPiN 1.2.3685-21. Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya (utv. postanovleniem Glavnogo gosudarstvennogo sanitarnogo vracha RF ot 28 yanvarya 2021 goda № 2) [Hygienic standards and requirements to providing safety and (or) harmlessness of environmental factors for people (approved by the Order of the RF Chief Sanitary Inspector on January 28, 2021 No. 2)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/573500115 (March 12, 2022) (in Russian).

[4] R 2.2.2006-05. Guide on Hygienic Assessment of Factors of Working Environment and Work Load. Criteria and Classification of Working Conditions (approved by G.G. Onishchenko, the RF Chief Sanitary Inspector on July 29, 2005). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200040973 (March 12, 2022) (in Russian); Ob utverzhdenii Metodiki provedeniya spetsial'noi otsenki uslovii truda, Klassifikatora vrednykh i (ili) opasnykh proizvodstvennykh faktorov, formy otcheta o provedenii spetsial'noi otsenki uslovii truda i instruktsii po ee zapolneniyu: Prikaz Mintruda Rossii ot 24.01.2014 g. № 33n (red. ot 27.04.2020) [On Approval of Procedure for conducting a special assessment of working conditions, Classifier of adverse and (or) hazardous production factors, reporting form on a specific assessment of working conditions and instructions how to fill it in: The Order issued by the RF Ministry for labor and Social Protection on January 24, 2014 No. 33n (last edited on April 27, 2020)]. *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_158398/ (March 12, 2022) (in Russian); MI NTP.INT-17.01-2018. Metodika izmerenii pokazatelei napryazhennosti trudovogo protsessa dlya tselei spetsial'noi otsenki uslovii truda (utv. prikazom General'nogo direktora AO «Klinskii institut okhrany i uslovii truda» A.V. Moskvichevym ot 06.12.2018 № 010-OD) [The methodology for measuring indicators of labor intensity within special assessment of working conditions (approved by A.V. Moskvichev, Managing Director of "Klinskiy Institute for labor protection and working conditions" JSC on December 06, 2018, the Order No. 010-OD)]. Moscow, 2018, 42 p. (in Russian).

All this calls for developing a new concept for assessing WI. This concept for assessing WI at workplaces of civil aviation pilots should rely on control of both functional changes in the body and indicators that provide evidence there is a relationship between occupational factors at pilots' workplaces and an elevated risk of aviation accidents as the most unfavorable outcome at these workplaces.

The concept for WI assessment will make it possible to cover all the specific features typical for flying. These features are associated with sensory, information, intellectual and emotional loads, work monotony and intensive working regimes, in other words, all this combined under the notion "work intensity". This will also help develop relevant activities aimed at improving the system for managing risks associated with fatigue.

Our research goals were to provide scientific substantiation for the WI assessment concept based on results produced by experimental studies of influence exerted by flying and associated loads on functional changes in the nervous system, cardiovascular system, and sensory organs of pilots; on a growing number of errors in work operations during a flight; on establishing a contribution made by fatigue to an increase in a risk of aviation accidents. Another goal was to develop recommendations on making relevant addenda into legal and regulatory documents.

Research materials and methods. The research involved applying analytical examinations, questioning, hygienic studies, time studies, psychophysiological studies, statistical and expert methods. We considered provisions stipulated by the State Standard GOST R ISO 10075-3-2009[5] when selecting the research techniques.

We accomplished experimental studies to assess the psychophysiological state of 120 pilots (aged 41 ± 8 years). The experiment involved simulating a flight using full-flight simulators for Boeing 737-800, Airbus A-320, and Sukhoi Superjet 100 aircrafts that account for 52 % of all the aircraft fleet in the RF civil aviation. Flights with their duration being 340 minutes were simulated based on real situations available in a simulator database (coordinates, height, speed, meteorological conditions, emergencies, etc.). The flights were standardized as per their duration and complexity. Overall, eight different stages in a flight were simulated, each lasting 15 minutes. Three stages did not involve any failures in flight and navigation systems in regular conditions (No. 1, taking off and climbing; No. 2, horizontal flight; No. 3, descending and landing). The other five stages simulated descending and landing with failures of flight and navigation systems in irregular conditions (No. 4, a strong crosswind and fog; No. 5, a strong crosswind, fog and an engine failure; No. 6, a strong crosswind, fog, an engine failure and going on to the second circle; No. 7, a fire in an engine and going on to the second circle; No. 8, a shift in a wind at 1200 meters, going on to the second circle, visual landing). The experiment gave an opportunity to assess errors made by pilots in their operations; the process relied on expert estimates provided by a flight instructor.

Time studies were accomplished in accordance with the Guide on Aircraft Flight Exploitation (GAFE). All the standard operational procedures included into the GAFE were divided into seven groups depending on involved sensory loads: a duration of concentrated observation; density of signals; a number of production objects that were to be observed simultaneously; observation of monitors; loads on the acoustic analyzer; monotony indicators; loads on the vocal apparatus.

We took simple and complex visual-motor reactions (SVMR and CVMR) to analyze operational working capacity and stability of sensorimotor reactions. To do that, we applied UPFT-1/30 "Psychophysiolog" device for psychophysiological testing ("Medicom MTD" NPKF LLC, Russia). We measured 12 indicators including an average reaction time (msec), a total number of errors, and a level of sensorimotor reactions.

Attention focusing was assessed using "BYIBOR" device ("KONTSEPTSYA" JSC. Moscow). We assessed the following indicators:

---

[5] GOST R ISO 10075-3-2009. Ergonomic principles of assuring the adequacy of mental workload. Part 3. Principles and requirements concerning methods for measuring and assessing mental workload (approved and validated by the Order of the Federal Agency on Technical Regulation and Metrology dated December 7, 2009 No. 585-st). *KODEKS: electronic fund for legal and reference documentation.* Available at: https://docs.cntd.ru/document/1200075947 (March 17, 2022) (in Russian).

a sum of correct key strokes (quantity); an average reacting time (ART) to signal signs (msec); SD (standard deviation); a sum of "alerting" errors; a sum of logical errors; a sum of omissions.

SMI ETG glasses-like mobile eye-tracker was applied to register and assess indicators of oculomotor activity. We assessed dynamic characteristics of fixations, saccades, and winks (quantity, duration, speed, and path curvature).

We used the same UPFT-1/30 "Psychophysiolog" device for psychophysiological testing ("Medicom MTD" NPKF LLC, Russia) together with Holter monitoring to examine the functional state of the cardiovascular system. Hear rate variability was estimated as per data on statistical, geometric and spectral characteristics.

We questioned 667 pilots and examined data on prevalence of chronic diseases among them. We also analyzed reports on aviation accidents and a contribution made to them by pilots' fatigue resulting from improper work and rest regimes. The reports were issued after 84 investigations of aviation accidents (AA) performed by the Interstate Aviation Committee (IAC) in 2010–2021 [3].

Nominal (qualitative) data were described with absolute values (how many times an indicator recurred in a sampling) and relative frequencies or percents (a percent of this value in the whole sampling). A hypothesis that values of an indicator conformed to normal distribution was tested using Kolmogorov – Smirnov test and Shapiro – Wilk test. Since this distribution was not normal in all the groups, we described them with median values (*Me*) and lower and upper quartile (Q_1; Q_3) calculated in Statistica 10.0.

Results. ***Time studies*** provided an insight into actual sensory loads pilots had to face during a flight. We calculated a number of signals[6] and messages received by a pilot at different stages in a flight, their density per minute/hour, as well as a period a pilot spent performing concentrated observation of the processes involved in a flight (Table 1).

Obviously, a number of signals received by a pilot, their density and a period of concentrated observation are extremely high. For example, during taking off and landing, both pilots had to perform constant control of speed, height, vertical speed, meteorological conditions shown by the locator, relief shown by GPWS, positions of other aircrafts shown by TCAS etc. Given this, values of the aforementioned indicators are far beyond any limits stipulated by regulatory documents[4] for harmful working conditions from the hazard category 3.2. Thus, a period of concentrated observation amounted to 98 %; density of signals

Table 1

Results produced by time studies of regular operational procedures performed by a pilot at different stages in a flight

Flight stages	Number of signals	Time, min	Density of signals per 1 minute / hour	A period of concentrated observation, %
Pre-flight preparations	493	20	25 / 1500	90
AC cabin preparation	1780	30	59 / 3540	100
Towing and starting the engine	603	18	34 / 2040	100
Taxiing	326	10	33 / 1980	100
Taking off	791	10	79 / 4740	100
Climbing	760	20	38 / 2280	100
Horizontal flight	2180	80	27 / 1620	90
Preparing to descend	377	10	38 / 2280	100
Descending	808	20	40 / 2400	100
Landing	361	5	72 / 4320	100
Taxiing after landing and switching the engine off	156	5	31 / 1860	100
Post-flight works	231	15	15 / 900	100
Total in a flight shift	8866	243	37 / 2220	98

---

[6] A signal was understood as excitation occurring under a specific state or a change in states of production devices that exerted influence on a pilot's sensory organs – visual signals (produced by optical indicators), acoustic signals (acoustic indicators) or signals perceived by skin (tactile indicators). The definition is taken from the MI NTP.INT-17.01-2018[4], item 3.1.7.

per one hour varied from 900 to 4740 at different stages in a flight (2220 per hour on average during a whole flight shift); a period during which pilots had to observe monitors exceeded six hours. Therefore, given all regular operation procedures according to GAFE, actual values of, for example, density of signals received by pilots turned out to be significantly higher than values stipulated by the existing regulations ("more than 300 signals'). This makes it necessary to assign pilots' working conditions into a category with higher harmfulness as per work intensity, namely the hazard category 3.3.

A number of signals received by a pilot during taking off, for example, requires reacting to them at a speed about 760 msec per one signal[7]. An experimental study showed that an average latent period necessary to select a proper reaction amounted to approximately 330–540 msec [4]. When actual tasks have been performed for a long period, a value of this indicator can grow by 2–4 times and fatigue is very probable. For example, a reaction time of a car driver from the moment a danger was detected to making a decision how to eliminate it varies from 0.4 to 1.6 sec; on average, 1 sec; in the worst scenario, 1.6–2 sec [5]. This reaction time allowed for civil aviation pilots should not exceed 0.5 sec since the density of signals is much higher. Therefore, a number of signals received by a pilot is at the very limit of psychological capacity of human analyzers. When a pilot experiences fatigue and faces substantial overloads due to working under such conditions, errors are very probable and even close to unavoidable.

More than 1000 incoming signals received by pilots per one hour in a flight shift allow concluding that this quantity is much higher than the same parameter for car drivers who receive approximately 700–800 signals per one hour of a work shift that lasts 7–8 hours [5]. Besides, car drivers do not have to observe monitors, to listen what is on the air or to speak with air traffic controllers. Pilots do it constantly using radio headsets. In addition, pilots cannot stop and get some rest in case they feel tired. Therefore, all the indicators prove that work performed by civil aviation pilots belongs to the most intensive ones and it is extremely vital to estimate a number of signals for providing flight safety. Difficulties in calculating a number of signals processed by a pilot during an actual flight are also related to the fact that accomplished procedures on flying an aircraft usually envisage several possible solutions to one task. It is especially true when an unforeseen situation or an emergency occurs (unfavorable meteorological conditions, technical problems, etc.).

According to some research works, it takes a lot of effort to assess sensory loads as per results produced by calculating incoming signals; in addition, such assessments bring a significant uncertainty into ultimate results. Calculation of information loads can become a way to integrally assess volumes of information a pilot has to process. These loads can be calculated using oculography (eye tracking). The maximum information flow of conscious sensory perception is known to be equal to approximately 40 bps[8]. This indicator has been established to be age-dependent since sensory perception goes down by approximately 40 % when a person reaches 60 years.

Issues related to measuring and hygienic assessment of information as a physical factor have been addressed in research works that concentrate on developing "information hygiene" as a specific trend in occupational medicine [6–8]. However, any tasks on determining information loads were solved in such works by using calculated prior methods and relied mostly on assessing volumes of text information produced by workers employed in different brunches on PC over one year. Later works highlight the necessity to compare information produced by people and perceived by them [9, 10]. However, we did not manage to find such studies in available literature sources.

In the present study, the task related to assessing information loads as well as outcomes of their influence on pilots' functional state was solved by using a comprehensive approach based on actual data obtained in experimental conditions. The study involved using psychophysiological techniques, health self-assessment, revealing correlations between WI and preva-

---

[7] Matranova I.N. Metodicheskoe rukovodstvo po psikhofiziologicheskoi i psikhologicheskoi diagnostike [The methodical guidelines on psychophysiological and psychological diagnostics]. Ivanovo, "Neirosoft" LLC, 2007, 216 p. (in Russian).

[8] Fundamentals of Sensory Physiology. In: R.F. Schmidt ed. 2nd cor. edition. Berlin, Springer-Verlag, 1981, 267 p.

lence of chronic diseases among pilots as well as occurrence of aviation accidents.

Experimental psychophysiological studies were accomplished in accordance with the approved protocol that envisaged growing intensity of flight loads from stage to stage.

Within the experiment, we performed eye movement testing, assessment of heart rate variability (HRV), CVMR/SVMR, and testing of attention focusing bound to errors in activities. This enabled us to correlate flight loads with functional changes in pilots' bodies as well as to identify exact quantitative volumes of processed information. This quantification considered how frequently one image replaced another on a monitor, information flows from other sources, and a number of multifunctional devices (Table 2). Emotional loads (stress-factors) were calculated as per a number of scheduled taking-offs / landings in difficult conditions with analyzing a number of errors in flying an aircraft.

Results produced by eye-tracking gave grounds for objective assessment of density of signals, a period of concentrated observation, a number of objects that had to be observed simultaneously and how pilots' attention was distributed to cover all of them. The estimated period of concentrated observation varied from 90 % (horizontal flight) to 100 % (pre-flight preparations, taking off, climbing and landing) at different stages in the experiment. The density of signals and messages on average amounted to 4500 per one hour, which is by 15 times higher than the criteria established for intensive labor belonging to hazard category 3.2 as per this indicator. A quantity of objects that should be observed simultaneously varied

Table 2

Indicators of sensory, information, intellectual and emotional loads for pilots in experimental studies with modeling actual flight conditions on a simulator

No.	LI indicators	As per stages in experiment			WI assessment criteria[4,5] for hazard category 3.2	New WI criteria for hazard category 3.3	Expert assessment of WI category (as per average values)
		min.	max.	average			
1	***Sensory loads*** A period of concentrated observation (% of a flight shift)	90	100	95	More than 75[4]	"More than 85"	3.3
2	Density of signals (light, acoustic, tactile) and messages (per 1 working hour during a flight shift, quantity)	5100	8400	4500	More than 300[4,5]	"More than 600"	3.3
3	A number of objects that have to be observed simultaneously (over a flight shift)	25	41	36	More than 25[4,5]	"More than 35"	3.3
4	Observation of monitors (hours per a flight shift)	4,1	6,2	6,1	More than 4/6[4]	"More than 8"	3.2
5	***Monotony*** A period spent on passive observation of a flight process (% of a flight shift)	0	7	6	More than 90[4]	"More than 95"	2
6	***Information loads*** A growing period of gaze fixation on a device (in %)	5	20	15	-	"More than 35" (n.i.*)	3.2
7	Frequency of images/volumes replacing each other on a screen (times/minute)	5	45	30	-	"More than 30" (n.i.*)	3.2
8	Information flow per a unit of time (bps)	5	40	25	-	"More than 100" (n.i.*)	3.2
9	***Intellectual loads*** A number of multifunctional devices (more than 10 bps)	4	4	4	-	"More than 8" (n.i.*)	3.1
10	***Emotional loads*** Work-related stress factors: errors in flying, action algorithm failure, taking offs / landing in unpredictable conditions (a number per a flight shift)	0	20	17	-	"More than 20" (n.i.*)	3.2

Note: *n.i. means this indicator is new.

from 25 (stage No. 2, horizontal flight) to 41 (landing, Nos. 3–6). According to these criteria, pilots' work can be assigned into the hazard category 3.3 as per its intensity.

Observation of monitors (recalculated as per a full regular flight shift) varied from 70 % (4.1 hours) during a horizontal flight to 100 % (6.2 hours) when an aircraft took off (stage No. 1) or landed (3–6, stages No. 5–8). We should note that criteria stipulated in the existing documents for this indicator[4] seem outdated and do not rely on a solid physiological foundation since the hazard category 3.2 covers such working conditions that involve observing visual displays (monitors) being equal to "more than 4 hours". At present, when almost each second workplace is equipped with PC, and information input or reading information on a monitor accounts for more than 50 % of a work time, these boundaries are to be shifted by two hours towards growing without distinguishing a particular type of displayed information. Observation of monitors for more than 8 hours per a work shift allows assigning working conditions into the hazard category 3.3.

A period spent on passive observation of a flight process varied from 0 % (taking off and landing) to 7 % during a horizontal flight. This means no monotony in this kind of work.

Images / values replaced each other on screens of flight and navigation equipment with frequency that was different at different stages in a flight and varied from 5 to 20 (on average 15) times per minute. Information flows per a unit of time varied from 5 to 40 (on average 25) bps. Four different multifunctional airborne devices (more than 10 bps) were used by pilots when different stages in a flight were simulated. These devices were the main flight display, multifunctional display, engine display and on-board computer; their use allowed us to determine intellectual loads pilots had to face. According to these indicators, pilots' work can be assigned into the hazard categories 3.2 and 3.1.

Therefore, three out of ten controlled WI indicators belonged to the hazard category 3.3; 5 indicators, the hazard category 3.2; one indicator, the hazard category 3.1; and only 1 indicator fell within the permissible category. This allows assigning pilots' work into the hazard category 3.3, which is confirmed by the WI indicators determined by simulating an actual flight conditions on a flight simulator.

We analyzed controllable psychophysiological CVMR indicators, attention focusing and HRV in dynamics. The analysis revealed authentic changes in aircraft captains and second pilots both at different stages and by the end of the experiment (Table 3).

The most distinct dynamics was detected in CVMR testing against the results produced by SVMR tests. CVMR testing revealed a decline in correctness by the end of the experiment

Table 3

Results produced by psychophysiological tests on flight simulators

Indicators		Stages in testing		P_{total} / $P_{1\text{-}8}$
		Taking off (Stage 1)	Landing 6 (Stage 8)	
Indicators taken in dynamics as per eye-tracking results				
A number of signals per minute		25.9 [22.1; 31.4]	27.1 [20.8; 35.1]	0.107 / 0.552
Path curvature		2.13 [1.87; 3.14]	2.18 [2.03; 2.35]	0.002 / 0.477
A number of fixations		1.49 [1.11; 1.62]	1.66 [1.51; 1.85]	0.002 / 0.091
CVMR indicators in dynamics				
Average reaction time (ARcT)		409 [390; 440]	461 [392; 558]	0.036 / 0.031
Level of sensorimotor reactions (LoSR)		4.00 [2.25; 5.00]	2.00 [1.25; 3.00]	0.014 / 0.017
Maximum reaction time (MaxRT)		631 [556; 723]	754 [590; 1132]	0.021 / 0.026
Indicators of attention focusing in dynamics				
Minimal reaction time (MinRT)		869 [816; 922]	892 [600; 1235]	0.041 / 0.859
Share of correct answers (SoCA)		100 [90.0; 100]	90.0 [90.0; 100]	0.369 / 0.026
HRV indicators in dynamics				
RMSSD	Aircraft captains	24.4 [22.1; 26.4]	22.9 [16.5; 31.0]	0.178 / 0.032
	Second pilots	35.2 [26.6; 42.8]	32.8 [25.6; 38.1]	0.300 / 0.678
	Both groups	26.4 [22.6; 39.0]	25.6 [20.9; 37.5]	0.131 / 0.085

Note: P_{total} is the significance level in comparing values of dynamic series as per all stages in testing (from taking off to landing 6); $P_{1\text{-}8}$ is the significance level in comparing indicators at the marginal stages in testing (only taking off and landing 6).

(by 16.5 %), a growing total number of errors (by 48 %), a growing number of incorrect reactions (by 58 %), a longer average reaction time (by 12.7 %), and a decrease in the integral reliability index (by 17 %).

The data provided by Table 3 and Figure 1 indicate that there was a statistically significant dynamics during all the stages in the experiment as per such CVMR indicators as ARcT (an average reaction time) and LoSR (the level of sensorimotor reactions). It is interesting that ARcT median values were growing steadily from the beginning of testing up to its end. The median had a strong direct statistically significant correlation ($r = 0.911$, $p < 0.001$) and its growth rates amounted to 19.5 %. LoSR median values declined steadily from the beginning of testing up to its end and were characterized with a strong direct statistically significant correlation ($r = 0.846$, $p = 0.002$), the decrease rate amounted to 50.0 %.

The results produced by analyzing various CVMR indicators in dynamics over the experiment had unidirectional trends. This indicates that changes were developing in the state of pilots' CNS including weaker perception and processing of afferent information as well as developing inhibitory processes. They determined lower effectiveness of the nervous system functioning, including cognitive one, lower working capacities, reliability and safety.

Tests on attention focusing revealed an apparent dynamics as per the minimal reaction time ($p = 0.041$) during all the stages in the experiment. However, we did not detect any significant differences in this indicator at the beginning and the end of testing ($p = 0.859$). A different dynamics was detected for a share of correct answers registered at each stage in the experiment. Inter-stage differences in the indicator were not statistically significant ($p = 0.369$) in most cases apart from differences between the marginal stages where they were statistically significant ($p = 0.026$). This means the indicators deteriorated and fatigue was developing: the median value of a share of correct answers went down by 10 % from the beginning to the end of testing.

HRV analysis established RMSSD to be the only indicator that correlated with the most significant SVMR indicators and attention focusing indicators. In particular, we revealed statistically significant correlations between RMSSD and a share of correct answers in attention focusing assessment ($r = 0.756$, $p = 0.030$) as well as between RMSSD and the average CVMR speed ($r = -0.786$, $p = 0.021$). These correlations indicate that in future these indicators (attention focusing, CVMR or HRV) might be introduced as new metrics in fatigue assessment (Figure 2).

The data provided in Table 3 clearly show that such indicators as path curvature and the number of fixations had statistically significant dynamics during all stages in testing. Their growth rates amounted to 2.21 % and 11.8 % for path curvature and the number of fixations accordingly (Figure 3).

The analysis also revealed a strong statistically significant inverse correlation (Figure 3) between RMSSD and such an eye-tracking indicator as the number of fixations ($r = -0.747$, $p = 0.033$).

The results produced by analyzing dynamics of psychophysiological indicators showed that fatigue was already present and

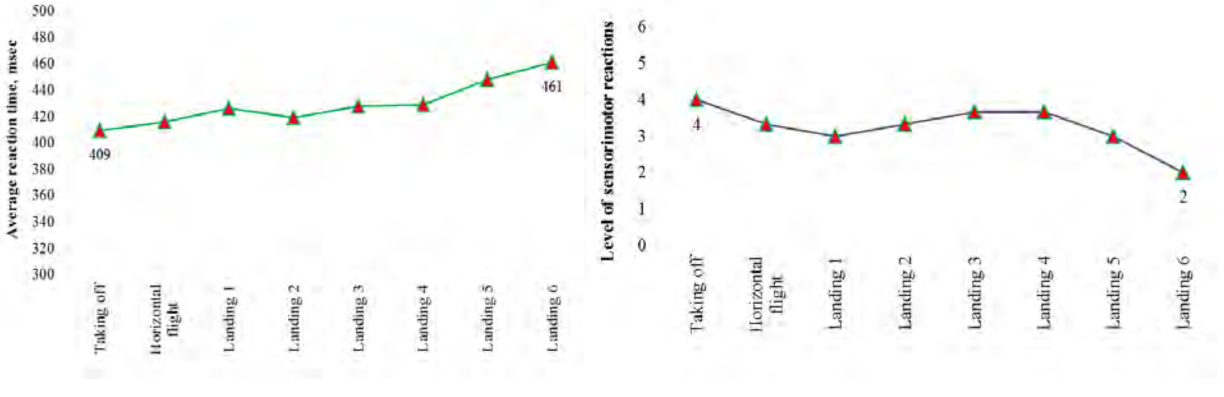

Figure 1. CVMR indicators in dynamics

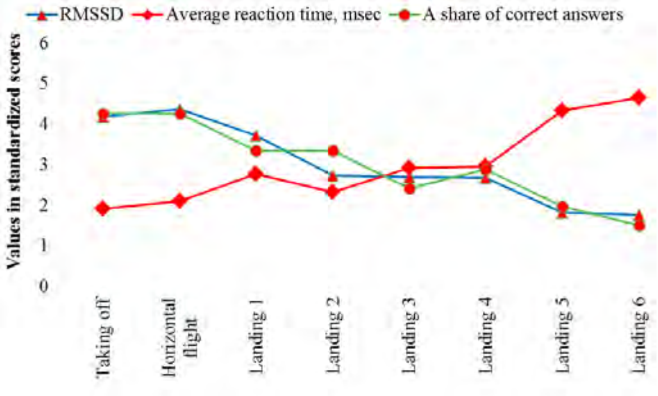

Figure 2. Assessment of correlations between HRV, CVMR and attention focusing

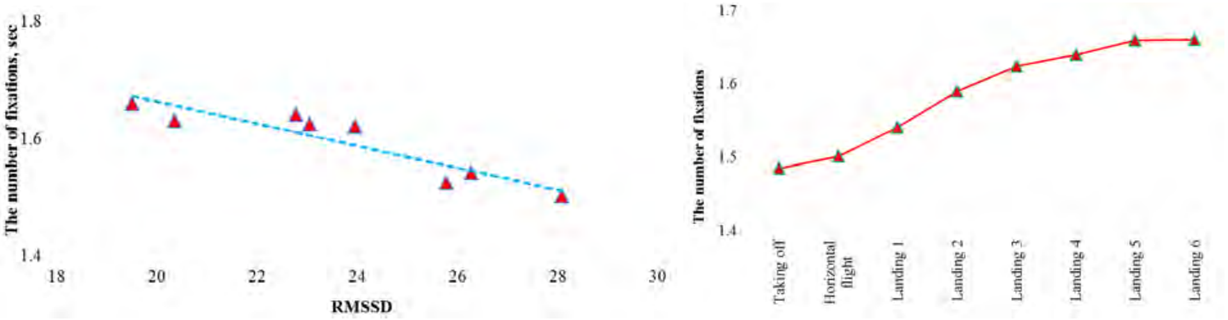

Figure 3. Eye tracking indicators in pilots in dynamics during the experiment

this involved a growing number of errors made by pilots in their operations. Each error was registered by flight instructors who were observing a simulated flight. Errors were detected in flying techniques, navigation, interactions and distribution of attention as well as in maintaining proper radio communication. The significance of these errors was conditionally estimated with scores from one to four (insignificant, correctable, gross or critical). The number and significance of the errors made by pilots turned out to be growing over the experiment and as loads intensified. By the end of the experiment, the differences between the initial and final stages in it were authentic, $p < 0.05$.

RMSSD had a strong and statistically significant correlation with the scores given to the errors ($r = -0.731$, $p = 0.040$). A similar trend was observed regarding correlations between the score given to the errors made by pilots and the share of correct answers in attention focusing assessment ($r = -0.722$, $p = 0.043$). We also detected statistically significant direct correlations between the score given to the errors and path curvature ($r = 0.922$, $p = 0.001$) as well as between the score given to the errors and the number of fixations ($r = 0.905$, $p = 0.002$).

Some aircrews made rather gross errors when flying (for example, they missed a height for going on to the second circle; they did not complete all proper preparations for landing using just one engine; they estimated a situation with engine failure incorrectly; they lost a proper height when landing etc.). The overall number of errors grew by the end of the experiment.

Therefore, the experiment performed on flight simulators involved modeling conditions that were closed to intensive sensory, information, intellectual and emotional loads pilots had to face when flying an up-to-date aircraft during a real flight. According to the level of these loads, pilots' work can be assigned into the hazard category 3.3 as per its intensity. Psychophysiological functions of a pilot can be at the level that imposes a threat to flight safety; the fact is confirmed by the data on errors made by pilots in flying techniques. Impairing psychophysiological indicators in the experiment dynamics were closely related to growing loads and this confirms that WI for pilots actually falls within the hazard category 3.3.

Development of a concept for WI assessment for pilots involved analyzing flight loads and detecting signs of fatigue; this was done based on pilots' self-assessment according to the recommendations by the International Civil Aviation Organization (ICAO) and in line with other research works [11]. According to these recommendations, ***we questioned 667 pilots.*** The results indicate that their work is accompanied with apparent intellectual, sensory and emotional loads and intensive working regimes. We established that more than 70 % of the pilots spent more than 75 % of the total flight time on concentrated observation of the devices; about 30 % of them received more than 300 signals (light or acoustic) per one hour on average during a flight; 60.5 % of the pilots crossed from 2 to 4 different time zones during one flight shift and 18 % of them crossed even more than 4. The pilots often highlighted lack of rest and sleep among factors influencing their fatigue: 1.7 % of them "never" had enough time to rest, 44 % "rarely" had it, and 60 % had only interrupted sleep between flight shifts and they had difficulty falling asleep. A share of pilots who could have episodes of "microsleep" during a flight amounted to 74.3–82.9 %.

The report issued by E.I. Surina, the leading expert on flight safety and human factor and a member of the IATA working panel on FRMS, stresses that it is significant to obtain relevant data on pilots' fatigue by using self-assessment [12]. Thus, according to data provided by voluntary reports (CAA, FAA, NASA), 90 % of pilots consider fatigue the key challenge in their work; they make 30 % of their errors due to fatigue; 7 % of them believe fatigue to be a factor that is hardly manageable with volition. According to some other data, aircraft captains were prone to having aviation accidents during flights that lasted longer than 12 hours (the US National Safety Transportation Board) and 20 % of such accidents are directly or indirectly associated with fatigue (FAA). Forty-three percent of pilots fell asleep at least once during a flight; 31 % stated that they found their second pilot asleep when they woke up (the British Airline Pilots' Association)[9]. According to Russian sources, aviation accidents caused by human factor accounted for approximately 80 % in 2020 as per all types of works [13].

According to questioning performed in Austria (85 %), Sweden (89 %), Germany (92 %) and Denmark (93 %), four out of five pilots feel tired at their workplace. Nevertheless, 70–80 % of pilots who had fatigue did not report fatigability or being incapable to fly [14].

Some factors that cause fatigue produce more apparent tiring effects. They are, for example, multiple taking offs and landings that tire a pilot more than just one flight with the same duration [15]; night flights or flights involving time zones crossing etc. [2, 16]; overtime works that are associated not only with fatigue but also with higher work-related injuries (by 61 %).

We analyzed ***health of civil aviation pilots using data on prevalence of chronic diseases among them.*** The analysis revealed that some diseases were caused by high WI. We detected high prevalence of chronic circulatory diseases (80.6 %), digestive diseases (38.4 %) and diseases of the nervous system (17.4 %) among pilots. They also had authentically higher risks that these diseases would develop (by 8.5, 4 and more than 17 times accordingly) against car drivers whose work is also rather intensive. These diseases were established to be associated with neuro-emotional and sensory loads and they could cause pilots' occupational incapacity, which was also confirmed by other studies.

Examining causes and circumstances of aviation accidents (AA) that occurred in civil aviation in Russia from 2010 to 2021 determined what contribution was made to them by fatigue and stress: 49.7 % of all AA were associated with human factor. Out of them, 8.4 % were caused by pilots' errors resulting from their fatigue due to improper work and rest regimes. In addition, some other factors increased risks of these accidents by 3–5 times: occupational noise, flights in dark, a night shift, total flying hours over a flight shift, month/year and even distribution of flight loads, duration of rest prior to a flight and an annual vacation.

We analyzed data on pilots keeping proper rest and work regimes as per data taken from reports on aviation accidents investigations. The analysis revealed that in some cases daily, monthly or annual standards of

---

[9] Sostoyanie bezopasnosti poletov v grazhdanskoi aviatsii gosudarstv-uchastnikov soglasheniya o grazhdanskoi aviatsii i ob ispol'zovanii vozdushnogo prostranstva v 2020 g. [Pilots' safety in civil aviation in the member-states of the agreement on civil aviation and air space use in 2020]. *The Interstate Aviation Committee*, 2021, 76 p. (in Russian).

flying hours were violated (from 2.4 to 12 % of cases as per different indicators). Duration of an annual vacation was also improper: almost one third of pilots did not have a vacation for over a year prior to an aviation accident; 18.5 % of aircraft captains had a vacation that lasted 10–29 days, 8 % of second pilots had a vacation of 1–9 days and another 16 %, 10–29 days. Flying hours over the last three days exceeded 13–16 hours in 6–10 % of cases (for both aircraft captains and second pilots), a number of landings varied from five to eight over the same period in 26.8 % of cases (and less than five in the remaining cases). Although we did not establish any violated standards for flying hours (permissible overwork considered), most of the aforementioned cases ended in air disasters. Obviously, improper work and rest regimes and excessive flight loads involve elevated risks of fatigue among pilots and lower flight safety.

Preventive activities aimed at health preservation, labor protection and prevention of accidents primarily rely on ***the legislative base***. A ground document for aircraft crewmembers is the Sanitary Rules SP 2.5.3650-20[10] that stipulates their working conditions as per only three factors. However, the profile of working conditions for airplane and helicopter crewmembers includes practically all known occupational factors and their levels can exceed permissible ones by multiple times. The existing situation is that most work-related factors at pilots' workplaces are not regulated and controlled, though hygienic standards are widely used by those who design and operates aircrafts and by heads of organizations responsible for providing regulated working conditions for pilots and control over their state at workplaces.

Meanwhile, it is well known that exposure to all occupational factors (especially noise, vibration, infrasound, unfavorable ergonomics of a workplace, or an uncomfortable working posture) make for fatigue development among workers[11] [17–19]. When they are not controlled, it does not make pilots' working conditions better or improve flight safety; we should also remember such a risk factor as "overworking", which aggravates their fatigue and neurotic trends [20].

The aforementioned sanitary rules have certain standards for providing safety at workplaces of workers employed by railways, sea and river ships and for air traffic controllers. This can be used as an additional argument for including relevant standards in the SR 2.5.3650-20[10] in the chapter that covers safety provision for air transport. As for vibration, we should note that its standard values for various aircrafts are stipulated in the valid State Standard GOST 23718-2014[12] and occupational diseases associated with exposure to vibration are detected in helicopter pilots. This makes control over this factor mandatory. Regulation of ionizing radiation that exerts its influence on jet plane pilots is included into ICRP, 60, part 1, item136v[13] and Sanitary Rules and Norms SanPiN 2.6.1.2800-10[14] .

Absence of requirements to work-related factors and factors of working conditions makes control over them impossible at workplaces. Due to this, the Order by the RF Ministry of Labor "On approval of peculiarities in accomplishing special assessment of working conditions at workplaces of crewmembers employed in civil aviation" has not been issued yet. A basic complexity in developing "SAWC peculiarities" for crewmembers working in civil aviation was absence of WI assessment criteria. As a

---

[10] SR 2.5.3650-20. Sanitarno-epidemiologicheskie trebovaniya k otdel'nym vidam transporta i ob"ektam transportnoi infrastruktury (utv. postanovleniem Glavnogo vracha RF ot 16 oktyabrya 2020 goda № 30) [The sanitary-epidemiological requirements for specific means of transport and transport infrastructure objects (approved by the Order of the RF Chief Sanitary Inspector on October 16, 2020 No. 30)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/566406892 (April 05, 2022) (in Russian).

[11] Suvorov G.A., Shkarinov L.N., Denisov E.I. Gigienicheskoe normirovanie proizvodstvennykh shumov i vibratsii [Hygienic standardization of occupational noise and vibration]. Moscow, Meditsina, 1984, 240 p. (in Russian).

[12] GOST 23718-2014. Passenger and transport airplanes and helicopters. Admissible levels of vibration in saloons and crew cabins and methods of vibration measuring (approved by the EEC and CIS Interstate Council for Standardization, Metrology and Certification (the meeting report issued on May 30, 2014 No. 67-P)). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200112158 (April 05, 2022) (in Russian).

[13] ICRP Publication 60. 1990 Recommendations of the International Commission on Radiological Protection. *Ann. ICRP*, 1991, vol. 21, no. 1–3.

[14] SanPiN 2.6.1.2800-10. Gigienicheskie trebovaniya po ogranicheniyu oblucheniya naseleniya za schet prirodnykh istochnikov ioniziruyushchego izlucheniya [Hygienic requirements regarding limitation of population exposure due to natural sources of ionizing radiation]. Moscow, Rospotrebnadzor's Federal Center for Hygiene and Epidemiology, 2011, 40 p. (in Russian).

result, necessary requirements are not included into aircraft operating manuals; prevention activities are not developed; problems occur when sanitary-hygienic profiles of working conditions are created; there are no objective grounds for developing a set of activities aimed at preventing fatigue in crewmembers.

Rest and work regime is another significant instrument for providing flight safety. This instrument is not effective enough at present. The Order by the RF Ministry of Transport[15] and the Regulation were issued 17 years ago and need revising. This is further confirmed by results produced by investigating reasons for AA, which showed that work and rest regime was violated in some cases. This led to fatigue among pilots and emergencies (approximately 9 % of AA cases). It is necessary to update the system for regulating work and rest regime and to implement up-to-date mechanisms for control of pilots adhering to it, international experience taken into account.

Discussion. Our analysis of the available regulatory documents indicates that the existing legal and surveillance base for standardization of working conditions at crewmembers' workplaces does not provide necessary control and mitigation of occupational risks. Neither makes it for improving pilots' health and preventing fatigue among them, high work intensity being the basic reason for it.

The comprehensive studies accomplished within this research work allowed us to develop this new concept for WI assessment when dealing with up-to-date intensive work tasks with typically high volumes of perceived and processed information as well as high speed of attention switch and decision-making. These work tasks set high demands for a worker's ability to perform sensorimotor activity under time deficiency. The concept includes a new approach to classifying labor intensity as per its hazard; introduction of the hazard category 3.3 for an indicator that describes sensory loads and for other indicators suggested for control of information, intellectual, and emotional loads (with quantitative criteria); alterations in the conceptual apparatus together with making relevant changes in the regulatory and legal documents. The suggestions have been developed on the example of assessing work intensity at workplaces of civil aviation pilots but they can be used for other occupations as well provided necessary adaptation to their specificity.

The concept is supported with the results produced by the comprehensive assessment of the existing working conditions for civil aviation pilots; analysis of pilots' functional state during a flight, which, among other things, included oculography, a method used for these purposes for the first time; data on prevalence of stress-factors among pilots; results of the questioning performed among crewmembers; as well as the results of assessing what contribution flying loads and fatigue made to occurrence of aviation accidents.

At present occupational morbidity has declined drastically and a probability that a grave occupational pathology would develop has become extremely low. At the same time, exposure levels that underlie assigning working conditions into a category with high hazard have not changed for many occupations; they have become even higher for WI. Work intensity does not have a direct correlation with developing occupational diseases; however, it can cause occupational incapacity and emergencies due to human factor. Such factors include not only WI but also microclimate, infrasound, electromagnetic fields, and lighting environment. Assessment of harmful working conditions as per all existing hazard categories, including 3.1–3.4 and 4, is stipulated for all the aforementioned factors, except WI.

According to ICD-10[16], issues related to work, in particular, "stressful work schedule"

---

[15] Ob utverzhdenii Polozheniya ob osobennostyakh rezhima rabochego vremeni i vremeni otdykha chlenov ekipazhei vozdushnykh sudov grazhdanskoi aviatsii Rossiiskoi Federatsii: Prikaz Mintransa Rossii ot 21 noyabrya 2005 g. № 139 (red. 17.09.2010 g.) [On Approval of the Regulation on peculiarities of work and rest regime for crewmember employed in civil aviation in the Russian Federation: The Order by the RF Ministry of Transport dated November 21, 2005 No. 139 (last edited on September 17, 2010)]. *KODEKS: electronic fund for legal and reference documentation.* Available at: https://docs.cntd.ru/document/901964448 (April 07, 2022) (in Russian).

[16] Mezhdunarodnaya klassifikatsiya boleznei 10-go peresmotra (MKB-10) (utv. prikazom Minzdrava Rossii ot 27.05.97 g. № 170 (red. ot 12.01.1998)) [International classification of diseases, 10th revision (ICD-10) (approved by the Order of the RF Public Healthcare Ministry on May 27, 97 No. 170 (last edited on January 12, 1998))]. *The international statistical classification of diseases and health issues, the 10th revision, online version.* Available at: https://mkb-10.com/ (March 18, 2022) (in Russian).

(ICD code Z 56.3) are among factors that are potentially hazardous for health and are related to psychosocial circumstances. This allows assigning the WI factor at workplaces (including those of civil aviation pilots) to work-related factors that can cause health hazards and this is fixed in the legislation.

WI induces unfavorable changes in workers' functional state thereby increasing occupational risks associated with injuries and emergencies. Given that, we suggest making the following alterations to determining the hazard category 3.3 of working conditions as per labor intensity.

The hazard category 3.3 (harmful working conditions, the 3rd degree) is applied to working conditions when a worker is exposed to harmful and (or) hazardous occupational factors exposure to which can induce such functional changes in a worker's body that can lead to developing occupational diseases with average or grave severity (including those with loss of working ability) and/or occurrence of chronic diseases caused by working conditions and/or high probability of an injury and an elevated risk of emergencies.

Intellectual load is a load when work is estimated considering intellectual activities performed by a worker. Intellectual load at workplaces of civil aviation pilots is assessed as per the number of multi-functional devices (more than 10 bps) in an aircraft cabin.

Information load is a quantitative measure of an information flow received by a worker per a unit of time, bps.

A multifunctional device is a device with an information flow going through it exceeding 10 bps.

This research has shown a possibility to perform objective assessment of visual signals using oculography (eye-tracking). However, so far there have been no available physiological criteria for assessing work performed by a pilot when this device is used. Our data gave an opportunity to suggest such criteria based on comparing oculography results and current sensory loads with results produced by simultaneous physiological studies that involved assessing SVMR, CVMR and HRV as well as with a number of errors made by a pilot when flying an aircraft as flight loads became more intensive. Oculography results were scaled as per intensity depending on signs of growing fatigue. This intensity was determined by an increase in a time of fixation on a device (in %), frequency of images/values replacing each other on a screen (times/minute), information flow volume per a unit of time (bps), and a number of multifunctional devices (more than 10 bps).

Specific indicators describing flight loads are especially significant in WI for civil aviation pilots. They include duration of a flight shift (which can exceed 10 hours when it comes down to long-distance flights); a number of taking offs and landings and a number of time zones crossed during one flight shift; a number of night flight shifts per week. These indicators are considered "work regimes". The criteria to assess them were developed based on work and rest regime regulations, results produced by investigating aviation accidents in civil aviation and pilots' health self-assessment.

Our research results indicate it is necessary to make ranges for the WI indicators wider and include the hazard category 3.3 for them.

Table 4 provides the criteria developed for assessing work intensity at workplaces of crewmembers.

Conclusions. The research results indicate that boundaries for hazard categories of working conditions as per indicators fixed in regulatory documents[4] are not sufficient for assessing WI at pilots' workplaces. This necessitated developing more precise criteria and introducing an additional hazard category of working conditions as per work intensity, 3.3, as well as developing new indicators for assessing information, intellectual and emotional loads.

We have developed new criteria for assessing WI for pilots who had to face highly intensive flight loads. These criteria are substantiated with the results produced by psychophysiological studies on flight simulators and confirmed by the questioning among aircraft crewmembers, detected regularities in prevalence of chronic diseases among them, and established cause-effect relationships with an increase in a risk of aviation accidents in civil aviation.

Given intensive flight loads pilots are exposed to, their psychophysiological functions can impair down to a level that imposes a threat to flight safety. This is confirmed by the data of physiological studies; errors made by pilots in flying techniques, navigation, distribution of attention, and radio communication

Table 4

Hazard categories of working conditions as per WI for civil aviation pilots

Indicator	Hazard category of working conditions			
	permissible		harmful	
	2	3.1	3.2	3.3
Sensory loads				
Duration of concentrated observation (% of a flight shift)	Less than 50	51–75	76–85	More than 85
Density of signals (visual and acoustic) and messages on average per 1 hour of a flight shift, units	Less than 175	176–300	301–600	More than 600
The number of objects that have to be observed simultaneously per 1 working hour	Less than 10	11–25	26–35	More than 35
Observation of monitors and devices (hours per a flight shift)	Less than 6	from 6 to 8	from 8 to 10	10 and higher
Duration of loads on the acoustic analyzer (hours per a flight shift)	Less than 6	from 6 to 8	from 8 to 10	10 and higher
Loads on the vocal apparatus (hours per week)	Less than 20	from 20 to 25	from 25 to 30	More than 30
Information loads				
Longer duration of fixation on a device (% of a total flight)	Less than 10	from 11 to 20	from 21 to 35	More than 35
Frequency of image/values changing on a screen (times/hour)	Less than 5	from 6 to 15	from 16 to 30	More than 30
Information flow volume per minute (bps)	Less than 5	from 6 to 10	from 11 to 100	More than 100
Intellectual loads				
The number of multifunctional devices (more than 10 bps)	1–3	4–5	6–7	More than 7
Emotional loads				
Work-related stress factors: errors in operation, action algorithm failure, taking offs and landings under unpredictable conditions (a number per a flight shift)	Less than 10	from 11 to 15	from 16 to 20	More than 20
The number of conflicts (per a shift)	Less than 3	from 4 to 6	from 7 to 9	More than 9
Monotony of loads				
Time spent on passive observation of a flight process (% of a total shift)	Less than 80	from 81 to 90	from 91 to 95	More than 95
Work regime				
Duration of a flight shift (hours)	Less than 8	9	10	More than 10
The number of taking offs/landings (per a flight shift)	1–2	3–5	6–8	More than 8
The number of taking offs/landings (per week)	1–6	7–10	11–14	More than 14
The number of night flight shifts (per week)	1–2	3	4	More than 4
The number of crossed time zones (per a flight shift)	1–3	4–5	6–7	More than 7
The number of crossed time zones (per week)	1–6	7–12	13–18	More than 18

maintenance during the experiment that involved modeling a flight on a flight simulator; and by the results of the accomplished questioning and data taken from reports issued after investigations of actual aviation accidents.

An efficient legislative base for regulation and control of pilots' working conditions, WI standardization that is adequate to actual flight loads, and established differentiated work and rest regimes are mandatory for mitigating occupational health risks for civil aviation pilots and preventing fatigue among them. The latter is a leading factor that can reduce risks of aviation accidents and provide flight safety.

Funding. The research was not granted any financial support.

Competing interests. The authors declare no competing interests.

References

1. Bukhtiyarov I.V., Zibarev E.V., Kuryerov N.N., Immel O.V. Sanitary and hygienic assessment of working conditions of civil aviation pilots. *Gigiena i sanitariya*, 2021, vol. 100, no. 10, pp. 1084–1094. DOI: 10.47470/0016-9900-2021-100-10-1084-1094 (in Russian).

2. Zibarev E.V., Bukhtiyarov I.V., Valtseva E.A., Tokarev A.V. Assessment of labor intensity indicators and factors affecting fatigue in civil aviation pilots based on the results of the questionnaire. *Meditsina truda i promyshlennaya ekologiya*, 2021, vol. 61, no. 6, pp. 356–364. DOI: 10.31089/1026-9428-2021-61-6-356-364 (in Russian).

3. Investigations. *The Interstate Aviation Committee (IAC)*. Available at: https://mak-iac.org/en/rassledovaniya/ (13.03.2022).

4. Kukushkin Yu.A., Ponomarenko A.V., Tsigin Yu.P., Stramnov S.B. Rezervy vnimaniya letchika kak otsenka protsessa podgotovki na aviatsionnom trenazhere [The pilot's attention reserves as an assessment of the training process on an aviation simulator]. *Chelovecheskii faktor: problemy psikhologii i ergonomiki*, 2007, vol. 38, no. 1–1, pp. 59–64 (in Russian).

5. Vaisman A.I. Fiziologicheskaya kharakteristika nervno-emotsional'nogo napryazheniya voditelei vo vremya upravleniya avtomobilem [Nervous-emotional stress of drivers while driving]. *Gigiena i sanitariya*, 1975, no. 6, pp. 13–16 (in Russian).

6. Denisov E.I., Prokopenko L.V., Eryomin A.L., Kourierov N.N., Bodiakin V.I., Stepanian I.V. Information as a physical factor: problems of measurements, hygienic evaluation and IT-automation. *Meditsina truda i promyshlennaya ekologiya*, 2014, no. 1, pp. 36–43 (in Russian).

7. Denisov E.I., Eryomin A.L. Information, health, innovations: hygienic aspects. *Vestnik RGMU*, 2013, no. 5–6, pp. 114–118 (in Russian).

8. Denisov E.I., Eryomin A.L., Stepanian I.V., Bodyakin V.I. Issues of measurement and estimation of information load at intellectual labour. *Neirokomp'yutery: razrabotka, primenenie*, 2013, no. 10, pp. 054–062 (in Russian).

9. Bukhtiyarov I.V., Denisov E.I., Eryomin A.L. Bases of information hygiene: concepts and problems of innovations. *Gigiena i sanitariya*, 2014, vol. 93, no. 4, pp. 5–9 (in Russian).

10. Zuev A.V., Fedotova I.V. Informational overstrain as a factor of occupational risk. *Bezopasnost' i okhrana truda*, 2015, no. 2, pp. 50–53 (in Russian).

11. Powell D., Spencer M.B., Holland D., Petrie K.J. Fatigue in Two-Pilot Operations: Implications for Flight and Duty Time Limitations. *Aviat. Space Environ. Med.*, 2008, vol. 79, no. 11, pp. 1047–1050. DOI: 10.3357/ASEM.2362.2008

12. Surina E.I. Razrabotka i vnedrenie sistemy upravleniya riskami, svyazannymi s utomleniem: doklad-prezentatsiya vedushchego eksperta po bezopasnosti poletov i chelovecheskomu faktoru, chlena rabochei gruppy IATA po FRMS [Development and implementation of a fatigue-related risk management system: report-presentation of a leading expert on flight safety and the human factor, a member of the IATA FRMS working group]. *Volga-Dnepr Group*. Available at: https://avam-avia.ru/wp-content/uploads/2020/02/41-surina-ei.pdf (14.02.2022) (in Russian).

13. Pilot Fatigue Barometer. *European Pilots Association AISBL*. Available at: https://www.eurocockpit.be/sites/default/files/eca_barometer_on_pilot_fatigue_12_1107_f.pdf (15.04.2022).

14. Honn K.A., Satterfield B.C., McCauley P., Caldwell J.L., van Dongen H.P. Fatiguing effect of multiple take-offs and landings in regional airline operations. *Accid. Anal. Prev.*, 2016, vol. 86, pp. 199–208. DOI: 10.1016/j.aap.2015.10.005

15. Olaganathan R., Holt T.B., Luedtke J., Bowen B.D. Fatigue and Its Management in the Aviation Industry, with Special Reference to Pilots. *JATE*, 2021, vol. 10, no. 1, pp. 45–57. DOI: 10.7771/2159-6670.1208

16. Dembe A.E., Erickson J.B., Delbos R.G., Banks S.M. The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occup. Environ. Med.*, 2005, vol. 62, no. 9, pp. 588–597. DOI: 10.1136/oem.2004.016667

17. Kandor I.S. Fiziologicheskaya stoimost' deyatel'nosti. Tyazhest' i napryazhennost' truda [Physiological cost of activity. The severity and intensity of labor]. *Fiziologiya trudovoi deyatel'nosti*. In: V.I. Medvedev ed. Saint Petersburg, Nauka, 1993, pp. 107–152 (in Russian).

18. Bodrov V.A. O probleme utomleniya letnogo sostava [On the problem of flight crew fatigue]. *Voenno-meditsinskii zhurnal*, 1986, no. 5, pp. 40–43 (in Russian).

19. Tomei F., Baccolo T.P., Tomao E., Palmi S., Rosati M.V. Chronic venous disorders and occupation. *Am. J. Ind. Med.*, 1999, vol. 36, no. 6, pp. 653–665. DOI: 10.1002/(sici)1097-0274(199912)36:6<653::aid-ajim8>3.0.co;2-p

20. Sechko A.V. Burnout in the stress system of aviation professionals. *Sovremennaya zarubezhnaya psikhologiya*, 2021, vol. 10, no. 1, pp. 102–110. DOI: 10.17759/jmfp.2021100110 (in Russian).

Zibarev E.V., Bukhtiyarov I.V., Kravchenko O.K., Astanin P.A. Development of a new concept for assessing work intensity of civil aviation pilots. Health Risk Analysis, 2022, no. 2, pp. 73–87. DOI: 10.21668/health.risk/2022.2.07.eng

Received: 11.05.2022
Approved: 27.05.2022
Accepted for publication: 21.06.2022