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BULGARIAN CONTRIBUTION TO RESEARCH OF HUMAN FACTORS IN SPACE

/55th Anniversary of the Space Research and Technology Institute, Bulgarian Academy of Sciences/

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Abstract

The article is devoted to the activities of the Space Research and Technology Institute of the Bulgarian Academy of Sciences (SRTI-BAS) in the field of human factors research. It focuses on the projects and achievements of the last 10 years. The available equipment and apparatuses in the laboratories of the Institute are presented, as well as the possibilities for solving various problems related to the training, selection, and evaluation of operators working in extreme conditions.

Introduction

For 50 years, the Republic of Bulgaria has established itself in the space family as the 6th country to send two cosmonauts - Georgi Ivanov and Alexander Alexandrov. The Space Research and Technology Institute at the Bulgarian Academy of Sciences (SRTI-BAS) works in almost all areas of space research with innovations and achievements in the field of space physics, remote sensing of the Earth and planets, space navigation and control systems, as well as in other areas of technical, physical and applied sciences [1].

This year marks the 50th anniversary of the launch of the first Bulgarian instrument, P-1, which was used for the first Bulgarian experiments in space. The P-1 instrument was designed for direct measurement of ionospheric plasma parameters and was launched into orbit on 1.12.1972 with the Interkosmos-8 satellite.

Space Biology and Medicine

An important event in the Bulgarian space activity is the preparation of the scientific program and the launch of the first Bulgarian cosmonaut, Georgi Ivanov. The flight took place on April 10-12, 1979, on board the spacecraft Soyuz 33

together with the cosmonaut Nikolai Rukavishnikov. On this occasion, the Sredets apparatus was developed and used on board the Salyut 6 space station to assess the psychophysiological state of the Soyuz 37 and Soyuz 40 crews.

During the flight of the second Bulgarian cosmonaut, the scientific and technical program "Shipka" was implemented, in which the Institute of Space Research of the Bulgarian Academy of Sciences played a leading role. During the joint flight to the orbital station MIR from 9 to 16.06.1988, the joint Soviet-Bulgarian crew conducted experiments in five scientific fields: space physics, remote sensing of the Earth and space, space biology and medicine, space materials science, and space engineering.

The medical-biological experiments of the Shipka scientific program included research on a wide range of problems related to the importance of the human factor in the functioning of the spacecraft-cosmonaut system. The Shipka programme conducted about 20 medical-biological experiments related to crew performance and developed five specialized on-board computer systems. The sensory-motor reactions of cosmonauts in space conditions, the distribution and switching of their attention in mental and motor activity, the state of higher mental functions, their emotional-volitional stability, and operational reliability were studied. The developed apparatus also allowed us to analyze the locomotor functions of the organism, the vestibular apparatus, the visual analyzers, the reactions of the human organism and a number of its specific parameters in the weightless state (Fig. 1). Experiments were conducted to observe all the peculiarities of the formation and realization of the astronaut's sleep during a real space flight.

Manned space flight is a complex research task that involves almost to the limit all psychophysiological, personal, and professional qualities and abilities of astronauts. For this purpose, the Pleven-87 complex was developed to study the psychophysiological reactions of the operator in ground and space conditions, which allows for defining criteria and norms for assessing the performance of cosmonauts during their stay in space. It proposes 15 tests/methods developed at OAMNII (Dr. Radkovsky) [2], and the microprocessor system was developed jointly with TU Sofia.

The Soyuz-U launch vehicle with the spacecraft Soyuz TM`5

Pleven-87 Complex

SON-3 Portable Magnetic Logger

ZORA system

LYULIN - Dosimetric device

Fig. 1. Medical and biomedical equipment from the Shipka program

The apparatus "SON-3" is a portable magnetic logger for sleep monitoring in space conditions, performing 12 hours of continuous recording. Sleep, nutrition, and radiobiological protection are the main factors on which the preservation and recovery of vital and neuro-mental functions of the human organism depend in microgravity conditions.

The Lyulin dosimeter is designed for active control of the radiation situation on the MIR orbital station. The Lyulin and Dose-B experiments are united by a common goal - research control and development of measures to prevent the effects of ionizing radiation on the body of cosmonauts.

The Zora apparatus was used to conduct a complex study of the neurophysiological state of man, changes in the functions of the vestibular

apparatus, the rate of innervation of muscle fibers, and coordination of limb movements in space conditions. In the Aerospace Engineering and Technology Section (ATT), in cooperation with German specialists, the complex for psychophysiological research Neurolab-B (Bulgaria is marked with "B"), shown in Fig. 2, was created. The apparatus investigates the psychophysiological responses of operators in complex environments by generating different levels of stress through logical problem solving and external stimuli. In its flight version, Neurolab-B monitors 48 channels (expandable to 128) that receive physiological information from various sensors placed on the operator [3] and in the space around him. Analyses are based on changes in trends of a number of vital physiological parameters, such as ECG, respiration rate, arterial blood pressure, skin-galvanic response, peripheral body temperature, changes in the basic tone of speech, facial expression and color, maximum strength of the muscles of both arms, eye muscle oculogram, against the background of solving various mental and visual tasks, including a simulation of docking the spacecraft to the station in manual mode. During operation, Neurolab-B is controlled by voice commands from the astronaut conducting the experiment. The device worked on board the MIR orbital station for 5 years until it was dropped into the waters of the Pacific Ocean. Almost all cosmonauts of different nationalities who stayed on the station during this period were examined with it. Subsequently, various medical devices such as ECG holders, sleep apnea analysis holders, electrocardiographs, pulse oximeters, and thermometers for remote measurement of body temperature were developed in the ATT (Aerospace Technics And Technologies) section of SRTI-BAS. They have successfully passed clinical tests and have been implemented in the Bulgarian health care system. On the occasion of the 60th anniversary of the Institute of Medical and Biological Problems of the Russian Academy of Sciences, Neurolab-B was mentioned as one of the excellent research devices designed for the study of the psychophysiological status of the astronaut operator.

Fig. 2. Complex for Psychophysiological Research Neurolab-B

Complex for selection and allocation of operators of complex machine systems. SRTI-BAS, together with specialists from other scientific organizations, has developed a complex system for selection and allocation of a certain contingent of candidates for operators of complex machine systems. The system can assign candidates to 50 classes (specialties).

The MIND expert system is a set of software tools for ranking and/or classifying certain criteria of objects (persons, candidates) into expertly predefined classes (specialties). The specialties are ordered by the user, and the results are displayed in various textual and graphical forms (Fig. 3).

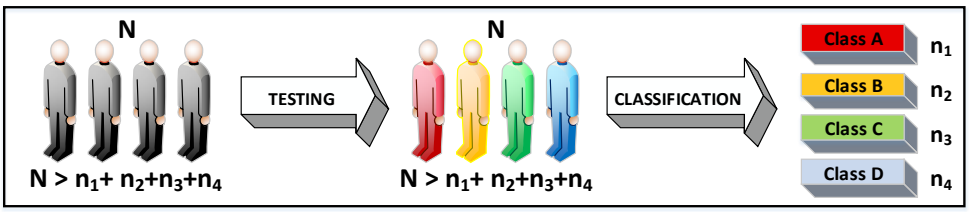


Fig. 3. MIND module

The system was implemented in 1990 in real conditions at the selection and distribution of conscripts in a conscription commission for 12 specialties of armoured and radar units.

At VTU T.Kableshkov and TU-Sofia, there are developments and publications on the problem of safety of the system "man-machine" (driver-engine, dispatcher-dispatcher centralization, traffic manager-gauge centralization, etc.) in connection with the railway transport process. In 1991, a locomotive driver training and control simulator was developed and implemented, consisting of three modules: 1) testing and checking the basic psychophysical qualities of candidates and trainee drivers; 2) learning the layout of electric locomotive systems and checking the knowledge; 3) training simulator for electric locomotive control with evaluation of the learned.

The Republic of Bulgaria is the third-largest producer of space food after Russia and the USA. The Bulgarian space menu (Fig. 4) on the joint Soviet-Bulgarian flights and during the implementation of the Shipka project was developed by the Institute of Cryobiology and Food Technology (ICFT) under the leadership of Acad. Tsvetkov [4]. Nutrition is one of the most important physiological factors with a determining role in maintaining a high level of performance, adaptability, and health of astronauts during long-duration space flights. The most typical unfavorable factors in the extreme conditions of working and living in space are weightlessness, increased pressure, high radioactivity, peculiar microclimate, high nervous-mental tension, limited motor activity, noise, vibrations, etc. An extremely important condition for overcoming the negative

processes in the organism of cosmonauts, which arise under the influence of the harmful factors of the long flight, is the quantitative and qualitative adequacy of food.

Fig. 4. Bulgarian space foods

As a continuation of this theme, in 2019 SRTI and the Institute of Cryobiology and Food Technology (ICFT) implemented a joint project with the European Space Agency (ESA) on the development and application of technology for the production of space food modules for crews working in extreme conditions (Space Foods) (PECS contract no. 4000126140/18/NL/MH) [5]. Two types of qualitatively new food modules, adaptogenic and biostimulant, were developed in one year for humans and crews working in extreme conditions.

Human Factors Projects

Human activity in space conditions represents a specific type of work performed in unusual and complex conditions, which in turn require habits and skills that ensure readiness to react to sudden atypical situations, ability to withstand stress, weightlessness, isolation, as well as management of mental behavior.

In this context, the research objectives focused on the study of the functional efficiency of people working in extreme conditions and the definition of the requirements and activities necessary for the process of selection, training, and supervision of operators of complex technical systems.

Contract with FNI (Research Fund) No. I 615/96 (1996-2000) entitled: "Research for the development of methods, algorithms, software and computer devices for the study of the operator of a complex technical system".

From the point of view of ergative systems (ES), the problems of the quality of functioning of complex systems and the requirement for high reliability

of the human being as a unit in them were analyzed. During the research, it was found that the causes of many operating errors, as well as equipment failures, are caused by the disturbance of information interaction in the man-machine system. A principled programming system for registration and analysis of occurring events was proposed. Computer models of the pilot-aircraft system were created, and the formalization of operator training processes, as well as their algorithmization and programming, were realized.

Contract with FNI № DTK 02-59/2009 (2009-2013) on the topic "Research on human functional efficiency in extreme conditions".

In the ES, the human is the critical unit that determines a number of essential system-wide qualities and parameters: reliability, speed, accuracy, repeatability, availability, robustness, adaptability, etc. An algorithmic model of the Human as a Control System (HCS) has been synthesized, which is considered a complex hierarchically organized control system on three levels: mechanics, control, and intelligence (Fig. 5).

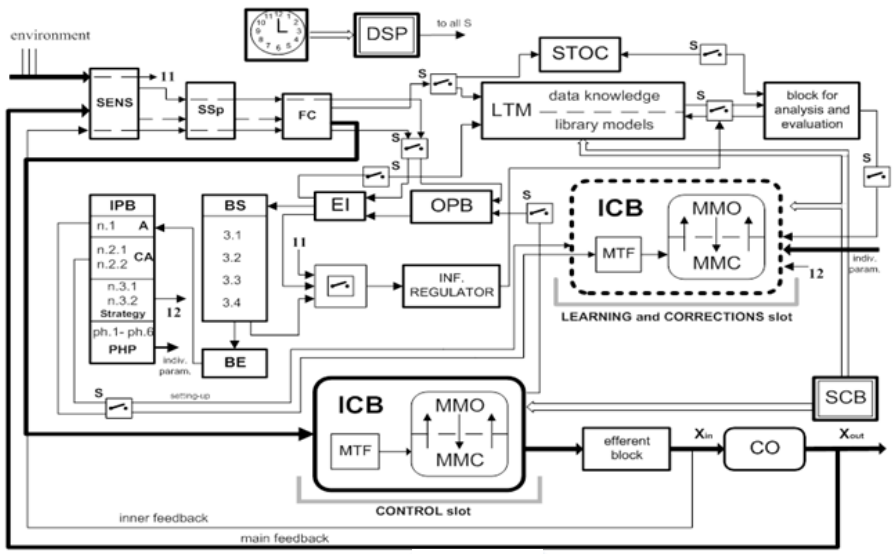


Fig. 5. Conceptual model of Human as a Control System

SENS *sensors;* ***SSp*** *sensor space;* ***FC*** *feedback classifier;* ***STOC*** *short-term and operative connections;* ***IPB*** *individual properties block;* ***A*** *activation (Yerks-Dodson type of activation);* ***CA*** *criteria adjustment (of precision, of speed);* ***PhP*** *physiological parameters (precision, speed, time delay, learn ability, efferent coordination, sensor status, etc.);* ***BS*** *block "significance" (with respect to time capacity, importance, complexity, risk);* ***BE*** *block "emotions";* ***BIC*** *block "information-control";* ***MTF*** *main transfer function;* ***MMO*** *mental model of the object;* ***MMC*** *mental model of the control;* ***EI*** *error indicator;* ***LTM*** *long-term memory;* ***OPB*** *operative prediction block;* ***SCB*** *slot for control of blocks;* ***DSP*** *dispatcher;* ***S*** *switch;* ***CO*** *control object.*

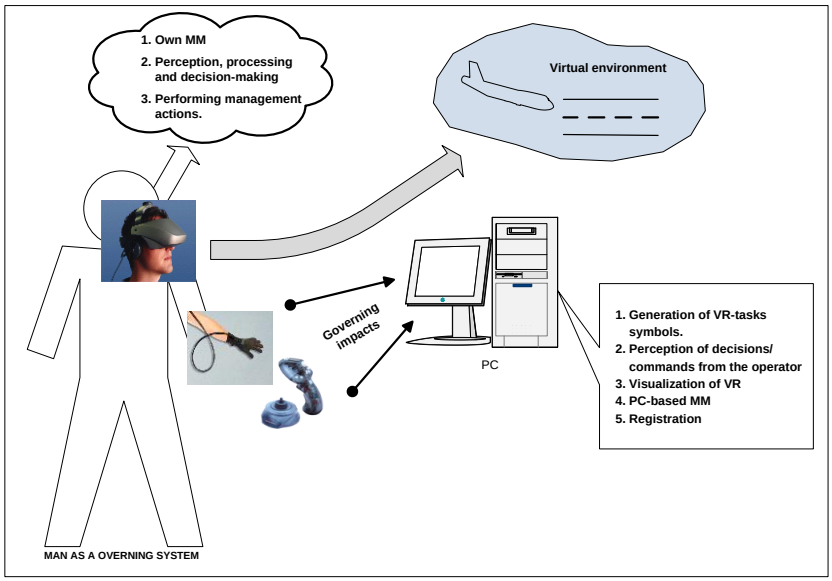


Fig. 6. HCS in a virtual reality environment

The closed-loop performance of the pilot during takeoff and landing was modeled in a "MATLAB-Simulink" environment [6]. To simulate the operator's activity, great attention was paid to the creation of a virtual reality based on different flight simulator software and the elements of the virtual system itself: helmet viewer EMagin Z800; data glove DG5 Vhand. Thanks to the five mounted flexion sensors, it is possible to accurately measure the movement of the fingers, and the triaxial accelerometer allows for measuring the movement and orientation of the hand (roll and pitch) (Fig. 6; Fig. 8, b).

The research complex BeOn-1 was created to study the human operator under the influence of operational environment factors [7] (Fig. 7 and Fig. 8, a).

Fig. 7. General view of the BeOn-1 Human Operator Research Complex

BeOn-1 is a computer-based experimental-application system used to study the situational alertness and behavior of aviation professionals - pilots, navigators, UAV operators - in a complex operational environment with extreme impact factors (Fig. 8, a).

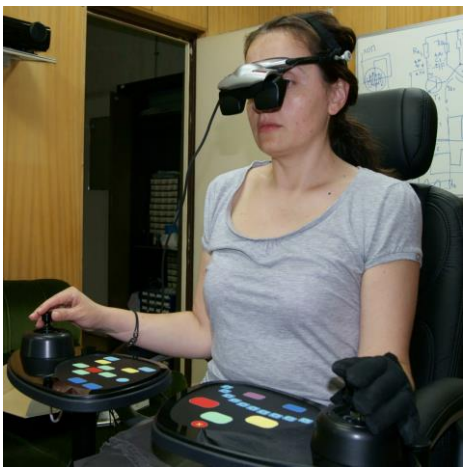
a)  b) 

Fig. 8. Complex BeOn-1 for human operator research

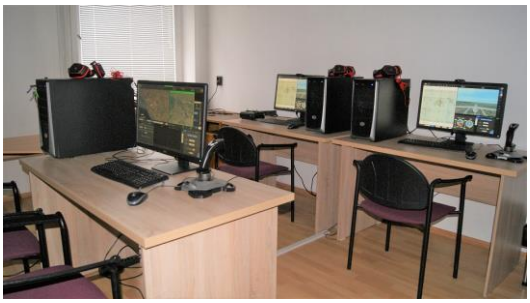
The laboratory testing of the research complex was carried out at the Scientific-Applied Center of Military Medical Expertise, Aviation and Naval Medicine - Military Medical Academy-Sofia.

Contract with FNI №KP-06/N27 (2019-2022) on "Human Factors in Remotely Piloted Aircraft Systems - Analysis, Evaluation and Selection".

Currently, the use of various unmanned aerial vehicles (UAVs) is expanding in most countries of the world due to their relatively low cost, versatility, and safety. They can be used in a wide range of applications: disaster and accident monitoring, emergency response, object and oil pipeline monitoring, forest patrol, etc.

The rapid growth in the number of UAVs and their increasingly widespread use makes operator training a problem in itself. This requires specialized equipment, separate training and flight schools, and separate training methods and methodologies. The modeling and study of the human being in organizational-technical systems is a highly topical interdisciplinary scientific problem that requires the use of the theory and methods of various branches of science: cybernetics, psychology, engineering psychology, physiology, ergonomics, mathematics, systems analysis, etc. Nevertheless, in recent years,

research and experimentation on the creation and use of unmanned aerial vehicles and the solution of the problem of operator selection, training, and control have been the priority for aviation worldwide (Fig. 9).



Laboratory for selection, training, and control of UAV operators at SRTI-BAS

Pupil Labs Core Mobile Oculograph Workstation

Analyzing the study and discussing the results

Workstation with GazePoint GP3 HD desktop oculograph and EMOTIV EEG

Fig. 9. Laboratory experiments with the C-Star simulator, SimLat

The main objective of the project was to determine and implement the capabilities of oculographic (eyetracking) methods to objectively (metrically) study the visual attention of UAV operators [8, 9].

A series of laboratory experiments were conducted with volunteers (trained, untrained) to implement a comprehensive practical process for the selection, training and control of UAV operators, and "flight benchmarks" were developed based on the resulting oculographic data to serve as a standard and dynamic control for the initial and periodic training of novice and professional UAV operators. The innovative experimental study combined two non-invasive methods, eye tracking and a wireless EEG device, confirming the hypothesis that certain cognitive functions, such as visual attention, mental workload, and emotional experiences of the participants, can be examined and measured with the level of stress at any moment of the flight.

Conclusion. Future research.

The human factor is directly relevant to the assessment of complex safety and as an interdisciplinary scientific basis is based on the laws, methods and criteria obtained in the fundamental fields of knowledge - mathematics, physics, chemistry, mechanics, informatics, mechanical engineering, biology, physiology, philosophy, sociology, psychology, economics, law. Generalized to the analysis of human factors are the development of systems analysis theory, chaos theory, control theory, catastrophe theory, simulation modeling methods, mathematical statistics, diagnostic and monitoring methods, and systems. Multidisciplinary research is now devoted to a wide range of issues in the fields of aerospace medicine and biology.

Starting from the understanding of the human factor as an object of study of various sciences, it is imperative to include work on the psychophysiology of flight work, aeronautical engineering psychology and ergonomics, the methodology of organizing aircraft maintenance in relation to flight safety requirements, and simulator training of engineering and technical personnel.

Modern psychophysiological methods reveal invisible and often unconscious processes of visual perception and decision making. The use of multisensory platforms to conduct research in psychology, cognitive and behavioral sciences, neuromarketing, and human physiology is now relevant. The need to combine neuroscience research and virtual reality (VR) in the formation of professional skills in the personnel training system is justified. The research is based on the study of the electroencephalogram of the brain in the process of training drivers, operators, dispatchers, etc. Patented, market-leading biosensor technologies provide the basis for biometric data analysis, providing a unique insight into a person's health, body, and mind.

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БЪЛГАРСКИЯТ ПРИНОС В ИЗСЛЕДВАНЕТО НА ЧОВЕШКИЯ ФАКТОР В КОСМОСА

/55 години Институт за космически изследвания и технологии– БАН/

З. Хубенова, С. Танев

Резюме

Статията е посветена на дейността на Института за космически изследвания и технологии-БАН (ИКИТ-БАН) в областта на изследването на човешкия фактор. Наблегнато е на проектите и постиженията през последните 10 години. Показана е наличната техника и апаратурата в лабораториите на института, както и възможностите за решавани на различни проблеми, свързани с обучението, подбора и оценката но оператори, работещи в екстремни условия.