**Scientific Journal of Silesian University of Technology. Series Transport**
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

**Volume 95** **2017**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2017.95.4

Journal homepage: http://sjsutst.polsl.pl

**Article citation information:**
Galant, M., Merkisz, J. Analysis of the possibilities of using EEG in assessing pilots' psychophysical condition. *Scientific Journal of Silesian University of Technology. Series Transport*. 2017, **95**, 39-46. ISSN: 0209-3324.
DOI: https://doi.org/10.20858/sjsutst.2017.95.4.

**Marta GALANT[1], Jerzy MERKISZ[2]**

# ANALYSIS OF THE POSSIBILITIES OF USING EEG IN ASSESSING PILOTS' PSYCHOPHYSICAL CONDITION

**Summary**. An excessive load on an operator's cognitive system can cause deterioration in perceptual abilities, decreased reaction time and increased probability of making an incorrect decision, which in turn can lead to a dangerous situation. Researching the cognitive load of an operator can therefore contribute to safer transportation. While there are many methods used in the study of cognitive load, they can be classified as either subjective assessments or objective assessments.

This paper presents an analysis of the possibilities of using electroencephalography in assessing the psychophysical condition of the pilot. The investigation was conducted in the Simulation Research Laboratory in the Institute of Combustion Engines and Transport at Poznan University of Technology.

**Keywords:** EEG; simulator; pilots' psychophysical condition.

[1] Institute of Combustion Engines and Transport, Faculty of Machines and Transport, Poznan University of Technology, Piotrowo 3 Street, 60-965 Poznań, Poland. E-mail: marta.m.galant@doctorate.put.poznan.pl
[2] Institute of Combustion Engines and Transport, Faculty of Machines and Transport, Poznan University of Technology, Piotrowo 3 Street, 60-965 Poznań, Poland. E-mail: jerzy.merkisz@put.poznan.pl.

## 1. INTRODUCTION

Cognitive load refers to the total amount of mental effort used in the working memory. A heavy cognitive load typically causes errors or some kind of interference in the task being conducted [11]. Excessive load may cause deterioration in perceptual abilities, decreased reaction time and increased probability of making an incorrect decision, possibly leading to dangerous situations that may result in an accident. Studies about cognitive load can therefore contribute to safer transportation. The only possible and effective method to avoid these risks is to monitor the operator's cognitive load.

The term "cognitive load" refers to the operator's demand on his or her cognitive resources. In a situation where demand exceeds a certain limit, the quality of the performance of tasks significantly decreases [1]. For a pilot, excessive cognitive load can result in the wrong selection of flight data, errors in the assessment of the situation, or problems with maintaining certain flight conditions. Appropriate monitoring of an operator's cognitive load could lead to a reduction in the number of errors made as a consequence of insufficient cognitive resources [6].

There are several methods used in studies of cognitive load, which by nature can be divided into subjective and objective assessment methods. Subjective methods includes the NASA-TLX questionnaire and the SWAT (Subjective Workload Assessment Technique). Objective methods are more frequently, which include measuring the heart rate and galvanic skin response, electroencephalography, functional magnetic resonance imaging, oculography studies, testing the activity of the cardiovascular system, the rate and depth of breathing, and positron emission tomography [5].

The article presents considerations for the use of the electroencephalogram (EEG) signal in studies involving the application of simulators. In recent years, simulators have become an inherent feature in research. The extent to which reality is represented by high-class simulators nowadays appears to be sufficient for laboratory research [9].

## 2. THE ESSENCE OF SIMULATION STUDIES

The issue of transport safety has inspired research, with the aim of improving the ability of operators (drivers, pilots etc.) and understanding the causes and relationships related to their behaviour. Often it is impossible or even too risky to recreate dangerous situations in order to analyse the causes of their occurrence. Therefore, for the purpose of research, simulators are frequently used. An important advantage when using simulators in research is the ability to control many factors, as well as record a number of variables, including the parameters of an operator's physiological and psychological condition [3, 7, 8, 13]. The use of simulators also allows for studies to be conducted, which can realize the full normalization of test conditions [4]. The repeatability of scenarios means that the behaviour of different operators under the same conditions or the same operator under different situations can be compared, which is not possible in real traffic conditions.

The dynamic development of simulation technology, as observed in the last two decades, has meant that the number of simulator applications has increased in all areas. Today, considerable attention is being paid to the way in which flight simulators can improve the level of aviation safety. Their advantages are particularly appreciated in the implementation of research and pilot training. There are known examples of when flight simulators are used to help trainee pilots master the techniques of piloting or warfare using military aircraft. As there are also types of aircraft for which tandem flight controls have not been produced, simulators offer the opportunity for complete training to be successfully carried out [12]. The use of flight simulators can significantly reduce the cost of pilot training. Besides teaching and training procedures, simulators can be used to conduct research and teaching in a wide range of disciplines.

Apart from the advantages, there are also some negative aspects to the use of simulators in research, such as simulator sickness. In addition, it often happens that an operator in a virtual environment becomes tired more quickly. However, the biggest disadvantage is in fact a feature that has been previously mentioned as an advantage: namely, safety. The operator in a simulator knows that he or she is safe, and there is nothing to be afraid of, which can cause him or her to perform manoeuvres that he or she would not perform under real flight conditions.

## 3. CKAS MOTIONSIM5 SIMULATOR

The Simulation Research Laboratory in the Institute of Combustion Engines and Transport at Poznan University of Technology is equipped with a CKAS MotionSim5 simulator. The device has been manufactured by CKAS Mechatronics Pty. Ltd. from Australia.

It is a system that uses software and hardware, combined with modern desktop computer equipment on a custom-built motion platform, comprising a cockpit that provides control devices that are identical or similar to those found on real aircraft. The MotionSim5 is a four-seater platform based on an electrical motion system with six degrees of freedom. This makes it possible to obtain a high level of accuracy in the performance of movement. The system tilts the hull in every possible direction at an angle of 18° and moves it 150 mm [2].

The MS5 Visual System, which provides a wide 200°×40° field of view with high resolution, consists of three full-HD (1,920×1,080 pixels) front-surface DLP projectors, three high-end PCs for image generation, and a screen. An additional PC is used to drive flight instruments and for general flight simulation.

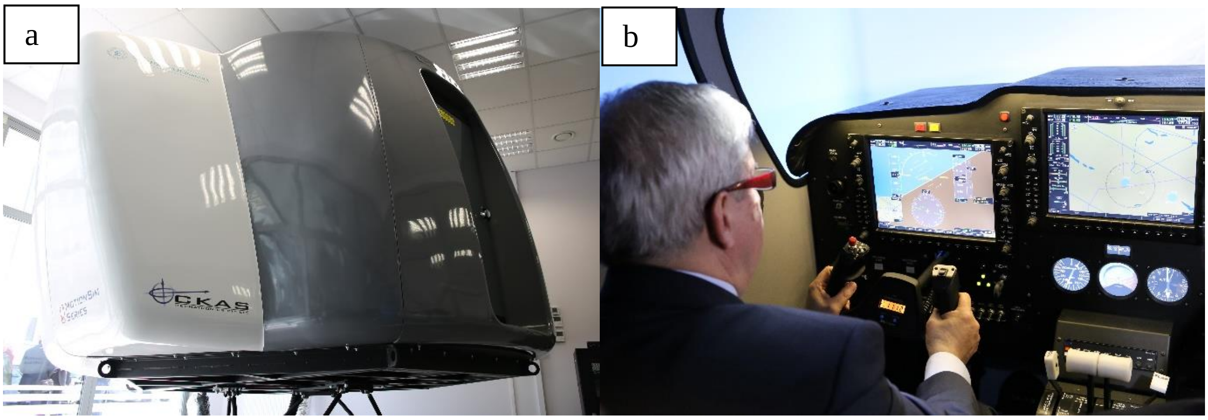


Fig. 1. CKAS MotionSim5 simulator: (a) exterior, (b) interior

The CKAS MotionSim5 trainer is designed to simulate four generic types of light aircraft: a piston single-engine aircraft, a piston twin-engine aircraft, a light twin-engine turboprop aircraft and a light jet. It is not intended to simulate a particular aircraft model, but rather to represent a typical aircraft in each class in terms of its handling qualities and features.

The Instructor Station provides control over the flight simulator environment, such as weather, positioning, malfunctions and real-time tracking and flight recording. Additionally, it is possible to carry out operations from and to almost every airport in the world.

The software allows for controlling the most important flight parameters: ALT (altitude), AGL (above ground level), IAS (indicated airspeed), VS (vertical speed), Bank (the angular displacement around the longitudinal axis, which passes through the plane from nose to tail [10]), Pitch (the lateral axis, which passes through the plane from wing tip to wing tip, with the pitch moving the aircraft's nose up and down [10]). After each flight, it is possible to record the parameters.

There are two kinds of generated files [2]:

– CSV file (to create personalized graphs), as presented in Fig. 2
– Google Earth file (showing the flight profile, events and mistakes), as presented in Fig. 3

Record start at: 01/06/2012 10:33:01

| Time (sec) | ALT (ft) | AGL (ft) | IAS (kts) | TAS (kts) | VS (ft/min) | N1 (%) | THR (%) | PITCH | BANK | AP | FLAPS | GEAR | SPOILERS | STALL | FAILURES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1800 | 1800 | 150 | 155 | 8196 | 115 | 100% | 45 | 5 | AP ON | Flaps + | | | | |
| 1 | 1800 | 1800 | 150 | 155 | 8196 | 115 | 100% | 45 | 10 | | | Gear Down | | | |
| 2 | 1800 | 1800 | 150 | 155 | 8196 | 115 | 100% | 45 | 10 | | | | | | |
| 3 | 1800 | 1800 | 150 | 155 | 8196 | 115 | 100% | 45 | 15 | | | | | | |
| 4 | 1900 | 1900 | 145 | 150 | 8026 | 115 | 100% | 45 | 15 | | | | | | |
| 5 | 2000 | 2000 | 140 | 145 | 7643 | 115 | 100% | 45 | 20 | | | | | | |
| 6 | 2200 | 2100 | 135 | 135 | 7053 | 115 | 100% | 45 | 25 | | | | | | |
| 7 | 2300 | 2200 | 125 | 130 | 6405 | 115 | 100% | 45 | 25 | | | | SPOILER DEPLOYED | | |
| 8 | 2300 | 2300 | 120 | 125 | 5606 | 115 | 100% | 45 | 30 | | | | | | |
| 9 | 2400 | 2400 | 115 | 120 | 4773 | 115 | 100% | 45 | 30 | | | | | | |
| 10 | 2500 | 2500 | 110 | 115 | 3910 | 110 | 100% | 40 | 35 | | | | | | |
| 11 | 2500 | 2500 | 105 | 110 | 2984 | 110 | 100% | 40 | 35 | | Flaps UP | | | | |
| 12 | 2500 | 2500 | 105 | 105 | 1829 | 110 | 100% | 40 | 40 | | | | | | |
| 13 | 2600 | 2500 | 100 | 105 | 1051 | 110 | 100% | 35 | 40 | | | | | | |
| 14 | 2500 | 2500 | 100 | 105 | 39 | 110 | 100% | 35 | 40 | | | | SPOILER ARMED | | |
| 15 | 2500 | 2500 | 100 | 105 | -1018 | 110 | 100% | 30 | 40 | | | | | | |
| 16 | 2500 | 2500 | 105 | 105 | -2026 | 110 | 100% | 30 | 40 | | | | SPOILER RETRACTED | | |
| 17 | 2400 | 2400 | 110 | 110 | -3070 | 110 | 100% | 25 | 35 | | | | | | |
| 18 | 2300 | 2300 | 115 | 115 | -4005 | 110 | 100% | 20 | 35 | | | | | | |
| 19 | 2300 | 2200 | 120 | 125 | -4933 | 115 | 100% | 20 | 35 | | | | | | |
| 20 | 2100 | 2100 | 130 | 135 | -5845 | 115 | 100% | 15 | 30 | | | | | | |
| 21 | 2000 | 2000 | 140 | 140 | -6648 | 115 | 100% | 10 | 25 | | | | SPOILER DEPLOYED | | |
| 22 | 1900 | 1900 | 150 | 150 | -7319 | 115 | 100% | 5 | 20 | AP OFF | | | | | |
| 23 | 1800 | 1800 | 160 | 165 | -7916 | 115 | 100% | 5 | 15 | | | | | | Failures: inhibit Flaps |
| 24 | 1600 | 1600 | 170 | 175 | -8393 | 115 | 100% | 0 | 0 | | | | | | Failures: Reverser 1 |
| 25 | 1500 | 1500 | 180 | 185 | -8742 | 115 | 100% | 0 | 0 | | | | | | Failures: GEN1Failures: NAV |
| 26 | 1300 | 1300 | 195 | 195 | -8997 | 115 | 100% | -5 | 0 | | | | | STALL | Failures: VACUUMFailures: GEN2 |

Fig. 2. Flight parameters (CSV file)

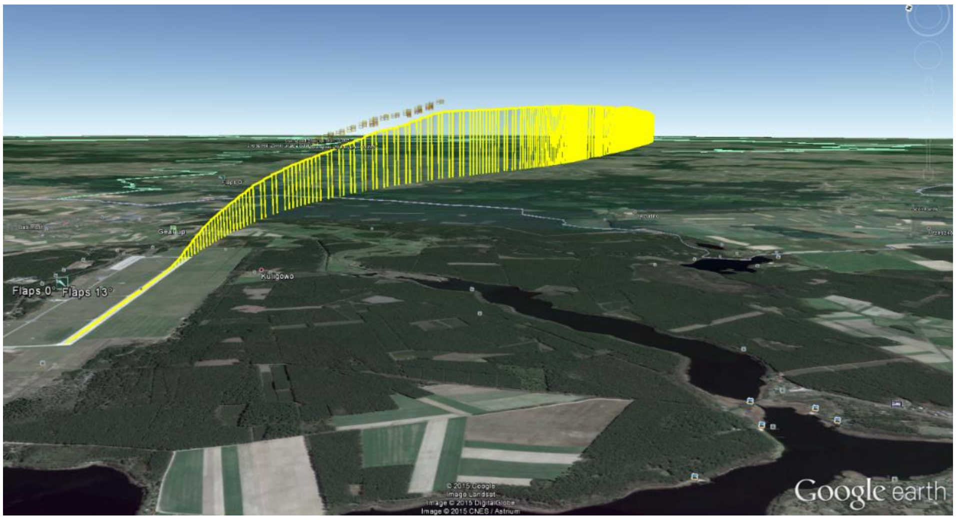


Fig. 3. Flight parameters (Google Earth file)

## 4. ELECTROENCEPHALOGRAPHY

Electroencephalography is a non-invasive method of neuroimaging, used to study bioelectrical brain activity with an electroencephalograph. An EEG is defined as a variable electrical activity, recorded from the surface of the scalp using the electrodes and conductive media [8]. EEG measurement is completely non-invasive procedure, which can be used on multiple occasions on one person, either an adult or child, practically without risks or restrictions. The electrical activity of the brain is formed by neuronal activity (related to the dissemination of information) [3]. Each nerve cell produces internal and external fluid surrounding the cell. This fluid is composed of water, protein and ions (positive and negative). As a result of a sufficiently strong stimulus, the cell membrane permeability changes occur for specific ions, while there are changes in the load inside and outside the cell, which are referred to as action potentials. The difference between the two potentials as a function of time is recorded by an EEG. In other words, an EEG records the voltage measurement resulting from brain activity [8].

In order to register the potential between the electrodes, at least two electrodes are required. For better results, more electrodes are typically used, which are placed at appropriate locations on the scalp. Electrode locations and names are specified by the International 10-20 system recommended by the International Federation of Clinical Neurophysiology. For a standard EEG, 19 recording electrodes (plus ground and system references) are used, with the graphic layout resembling a wavy line, in order to capture changes in the amplitude of the electrical activity of the brain in a certain period of time. The amplitude is typically expressed in microvolts (mV), while frequency is expressed in hertz (Hz).

Cyclic bioelectric activity of the brain, which is recorded during the test, is expressed in waves with a frequency in the range of 1-100 Hz and an amplitude of five to hundreds of microvolts. A normal adult's EEG is usually measured in terms of standby, with closed eyes, and in the course of performing a task. Recording with closed eyes and standby usually consists of a regular and dominant alpha wave, whose amplitude decreases from the occiput to the front of the head. Recording individual frequency corresponds to a specific mental state [8, 14].

The basic types of brain waves are as follows [3]:

- Delta wave (δ) (0.1-3 Hz)
- Theta wave (θ) (4-7 Hz)
- Alpha wave (α) (8-15 Hz)
- SMR wave (12.5-15.5 Hz)
- Beta wave (β) (16-31 Hz)
- Gamma wave (γ) (32-100 Hz)

The extent of the research and observations determines what information can be obtained from the images of brain waves. Studying the bioelectrical activity of the brain can be seen in whichever state is examined. However, there are also negative results for particular waves:

- Alpha waves are responsible for the state of relaxation, so its excess in the record indicates disorders manifested by a lack of motivation to work, as well as apathy, poor concentration and distraction.

- Beta waves indicate the rhythm of readiness and are divided into beta 1 and beta 2. Beta 1 is the state when the brain works quickly and efficiently; it depends on human will. Meanwhile, beta 2 is a very fast wave. This may reveal evidence of the excessive stimulation of the brain and nerve structures, which is reflected in impulsiveness, hyperactivity, aggressive and rebellious behaviour. This occurs in states of excitement, tension, nervousness, insomnia, irritability, trouble and anxiety.
- SMR is a sensory rhythm responsible for the storage and retention of information. When accompanied by extended learning processes, it helps to maintain the equilibrium of the nervous system.
- Gamma waves occur during associative processes and periods of intensive thinking.
- Theta waves are accompanied by processes of meditation, hypnosis, intense dreams and emotions. At this frequency, awareness can control physical pain, while the course of thoughts becomes inconsistent. Logical relationships disappear, as seen in the case of mental processes during sleep. Occurrence of a theta wave leads to a reduction in stress, as well as increased creativity, awakened intuition and memory.
- Delta waves appear during intense mental effort and deep sleep.

The correct EEG in humans at rest with closed eyes should consist mainly of alpha and beta rhythm. In healthy people, theta waves are recorded or the record is flattened. Any distortion, disappearance or asymmetry of rhythm, as well as the presence of pathological waves (theta, delta and other complex elements), confirms an incorrect test result.

The advantages of electroencephalography are as follows: relatively low cost, non-invasive and perfect time resolution. EEG observation allows for keeping track of which areas of the brain are active, although EEGs offer poorer spatial resolution. The EEG has clinical applications in humans and animals in order to [7]:

- Monitor alertness, coma and brain death
- Locate the area of damage after a head injury etc.
- Explore delivery paths (according to evoked potentials)
- Monitor cognitive involvement (alpha rhythm)
- Explore epilepsy and locate the source of attacks
- Monitor the development of the human and animal brain
- Study the effects of drugs on the formation of convulsions
- Study sleep disorders and physiology
- Given its wide-ranging uses, electroencephalography has contributed to the popularization of the method and the frequent use of EEGs in scientific experiments.

## 5. SUMMARY AND A DIRECTION FOR FUTURE WORK

The Simulation Research Laboratory in the Institute of Combustion Engines and Transport at Poznan University of Technology was created to conduct research, with the aim of improving the safety of air transport. The scope of activities within the laboratory currently consists of three basic areas:

1) Studying the influence of pilots’ psychophysical condition on flight safety
2) Analysing the proper operation of systems supporting pilots
3) Examining the suitability of a person to perform tasks

As demand to reduce the human factor in accidents is still high, there is a growing interest in flight simulators for training and research into pilots' psychophysical condition. Thanks to modern solutions, it is possible to examine changes in concentration, reaction time etc. without compromising on direct threats to life and health, which would be the case with research conducted under real-world conditions. An additional advantage of this type of research is the ability to reproduce the same conditions for an entire research group, which world would be impossible in reality.

The article has analysed the possibility of using the EEG signal to assess pilots' psychophysical ability. With this method, the level of concentration and relaxation, depending on the performed task, can be estimated, while the effect of weather conditions or the complexity of tasks on flight safety can be determined.

In the future, work is planned to use other methods for the objective assessment of pilots' psychophysical condition. For example, it is planned to use EyeTracker to measure eye movement.

This publication aims to present the research capabilities of the Simulation Research Laboratory at Poznan University of Technology.

## References

1. Patten C.J.D. 2007. *Cognitive Workload and the Driver: Understanding the Effects of Cognitive Workload on Driving from a Human Information Processing Perspective*. Stockholm: Department of Psychology, Stockholm University. Sweden.
2. CKAS. 2015. *MotionSim5 FSTD Operations Manual*. Melbourne: CKAS.
3. Małyszko-Mikołajek Grażyna. 2006. *O Terapii EEG Biofeedback*. Warszawa: Specjalistyczna Poradnia Psychologiczno-pedagogiczna. [In Polish: *EEG Biofeedback Therapy*. Warsaw: Specialized Psychological-Pedagogical].
4. Merkisz Jerzy, Jarosław Markowski, Marta Galant, Dominik Karpiński, Bartosz Orszulak.2014. "Ocena czynników wpływających na występowanie choroby symulatorowej podczas treningu na symulatorze AutoSim AS 1200-6." *Logistyka* 2. [In Polish: "Evaluation of factors influencing the onset of disease simulators using AutoSim AS 1200-6 training simulator". *Logistics* 2]. ISSN: 1231-5478.
5. Merkisz Jerzy, Jarosław Markowski, Paweł Fuć, Marta Galant. 2015. "Przegląd metod pomiaru obciążenia zadaniowego operatora w badaniach z wykorzystaniem symulatorów." *Logistyka* 3. [In Polish: "Review of methods for measuring the task operator's load in studies using simulators". *Logistics* 3]. ISSN: 1231-5478.
6. Merkisz Jerzy, Marta Galant, Dominik Karpiński, Bartosz Orszulak. 2014. "Wykorzystanie Aparatu Piórkowskiego do oceny porównawczej zdolności psychomotorycznych kierowcy przed i po treningu symulatorowym". *Logistyka* 4. [In Polish: "Using the Camera Piórkowskiego to comparatively evaluate the psychomotor ability of a driver before and after simulation training". *Logistics* 4]. ISSN: 1231-5478.
7. Jukiewicz Marcin, Jerzy Merkisz, Bartosz Orszulak. 2014. "Wykorzystanie urządzenia Mindwave do biopomiarów wskaźnika koncentracji w pracy badawczej związanej z symulatorem pojazdu osobowego". *Logistyka* 3. [In Polish: "The use of the Mindwave device to concentration ratio in research involving a passenger vehicle simulator". *Logistics* 3]. ISSN: 1231-5478.

8. Thompson Michael, LyndaThompson. 2003. *The Neurofeedback Book: An Introduction to Basic Concepts in Applied Psychophysiology*. Denver: Association for Applied Psychophysiology and Biofeedback. ISBN: 1887114068.
9. Niezgoda Michał, Tomasz Kamiński, MonikaUcińska, Mikołaj Kruszewski. 2011. "Effective methods for drivers research with use of a driving simulator." *Journal of KONES Powertrain and Transport*, Vol. 18, No. 3. ISSN: 1231-4005.
10. NASA. 2015. "Aircraft rotations: body axes". Available at: http://www.grc.nasa.gov/WWW/K-12/airplane/rotations.html.
11. Kirschner Paul A., John Sweller Richard E. Clark. 2006. "Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching". *Educational Psychologist* 41(2). ISSN: 0022-0663.
12. Zagdański Zbigniew. 1995. *Stany Awaryjne Statków Powietrznych*. Warszawa: Wydawnictwo Instytutu Technicznego Wojsk Lotniczych. [In Polish: *Emergency Aircraft Conditions*. Warsaw: Institute of Technology Air Force]. ISBN: 83-900817-3-3.
13. Jurecki Stanisław, Tomasz Lech Stańczyk, Marek Jacek Jaśkiewicz. 2017. "Driver's reaction time in a simulated, complex road incident". *Transport* 32(1):44-54. DOI: http://dx.doi.org/10.3846/16484142.2014.913535.
14. Gyliene Virginija, Neringa Kraptavičiūtė, Pawel Lipinski, Sebastian Wronski, Jacek Tarasiuk, Adriant Baldit, Rachid Rahouadj, Giedrius Gylys, Kristina Norkaitytė. 2016. "Vibrational and numerical evaluation of Human Incus properties". *Mechanika* 22(6). DOI: http://dx.doi.org/10.5755/j01.mech.22.6.16600.

Received 11.02.2017; accepted in revised form 27.04.2017