Human Factor Analysis in Unmanned Aerial Vehicle (UAV) Operations

Aeromedical and Physical Approach

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Abstract In Hungary Unmanned Aerial Vehicle (UAV) studies have a new momentum from a research project on Critical Infrastructure Protection (CIP). A Hungarian research team from the National University of Public Service made an attempt to address the UAV's human factor related safety issues, as selection, training and licensing. In UAV operations the achievement of an operational task is highly dependent on the operators' proper physical and mental performance, sensomotoric skills and abilities, so a medical screening shall be incorporated into the general selection process. The medical requirements naturally can differ from the physiological parameters of the pilot performing real flight because the weighted importance of aeromedical stressors and the level of flight safety risk are different. The evaluation of mental and physical performance and assessment of stress tolerance might be crucial from flight safety and operational aspects. The importance of simultaneous evaluation of cognitive performance, accompanying psychic stress and vegetative stress indicators is also emphasized.

Keywords Flight safety · Critical infrastructure protection · Remotely piloted aviation · Aircrew training · Psychic stress tolerance · Physiological parameters · Heart rate variability · Flight simulator

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1 Introduction

The UAV proliferation these days is not a question. UAV’s beside their military applications are obvious to use as CIP elements for example political and state administration centers, hazardous facilities, power plants, important economical facilities etc. Though developing UAV operations for state purposes on one hand can be very effective, the other hand for instance their safely integration in the conventional air traffic raises many questions. Its complexity and the rate of its permanent development and growing diversity of UAV operations are now projecting some safety conflicts with the conventionally piloted aviation system in the near future. A drone flying on a surveillance mission over a place crowded with people or over a nuclear facility could be both a defense element and even a threat, when something goes wrong. A crashing UAV can weigh over a 150 kg and has the kinetic energy to take lives and ruin vulnerable elements of the state infrastructure.

Flight safety is traditionally based on three factors: as on technical factors (aircraft, systems, airports, maintenance etc.), environmental factors (weather, natural phenomenon) and human factors, which are the more important of all.

Besides the technical development there are great potentials and possibilities in the development of human elements of the UAS. The selection, training, and licensing of UAV crews so far have not been fully covered by the national law. Though, their scientifically based definition would be a good token of operational safety. That is why our research is headed to a solution of ending those deficiencies.

Safety, even in the case of UAV flight, still lies in human hands. From a small harmless model up to a globetrotter combat UAV regardless to their control method cannot be flown without a certain rate of human control. The main decisions during missions are made by a human element. Finally, let it be a direct controlled or just overseen UAV mission the safety itself finally are guaranteed by the aircrew. Without them the most sophisticated technical systems are just useless having no decision making capability during flight and in emergency. The ability, quality of the human element means the basis of safety.

Therefore, the aircrews were put in the focus of studies, by using the following hypothesizes:

- UAV mission safety is basically determined by human elements of the system; UAV pilots should be considered as full pilots; and they may have overlapping in competencies with other professionals within the aviation domain; UAV crews should be differentially licensed according to aircraft category, type and mission.
- Among the physical skills, in addition to the basic level of conditional skills, complex coordination skills play a defining role in the skill development of UAV operators.
- In coordination and psychomotor skills tests, pilots perform better than the average of other control group.
- Stress tolerance might be used as a parameter for UAV operator working ability: good operator might have a better stress tolerance, solving the task at lower

stress level. Positive correlation is supposed between favorable (closer to normal range) physiological parameters, better results in standard psychological instrument tests and better performance in simulated flight tasks on ground-based simulator. In this case, the subject is capable to perform the same task at lower stress level (possibly in real UAV mission as well).

The questions for which our studies try to find the answers are the following:

From human factors' aspect could it be possible to provide a same level of safety as conventional flights during UAV operations? Could a UAV flight be as safe as a conventional flight while the technical, personnel requirements and rules—if they even exist—are far more forgiving than those for conventional ones?

2 Research Methods

During our studies on UAV HF, conventional research methods seemed to be the most appropriate, like document analysis (reports, monographies, articles, statistics), critical adaptation (existing operational procedures) and personal interviews with UAV personnel. As for the HF studies taking the existing technical level (safety, reliability) theoretically constant and excluding a changing element of the system seemed to be a feasible simplification. While different characteristics of UAV categories were taken into account. Likewise, the environment is considered as still and limited (horizontally and vertically limited, appropriate weather conditions). This way HF could be taken under a deep scrutiny without being disturbed by volatile elements of the system.

The research was conducted in different directions as:

– UAV crew member selection protocol (medical, suitability for aircraft control, pre-qualification)
– UAV crew training minima and optima according to mission (military, police, disaster control) and aircraft category (VLoS-BLoS, control method)
– Crew Resource Management of UAV
– Simulations in selection and UAV crew training
– UAV crew licensing criteria (medical, qualification, level of proficiency)

3 Using a Simulator in Experiments, Training and Selection

The simulator console used during our tests is a self-designed one. Its development was led by the aspects of the research. The idea of having a simulator console originates from the need for testing persons and measuring their abilities during the selection phase. The simulator is also suitable for observation their development in

UAV control even in VLOS (Visual Line of Sight) and BLOS (Beyond Visual Line of Sight) mode. Meeting these needs, the team decided on utilization of simple RC training software for external pilot view and flight simulator software for internal pilot view. The console itself is also a central factor in the medical tests when the subject persons' physiological functions (heart rate, saturation, skin resistivity etc.) are measured and recorded during simulated emergency situation. Since simulators usually are stationary and expensive, the research group decided on a different approach providing flexibility in usage and cost efficiency. It contains a high performance notebook, with two pieces of simulation software installed and with special controls for different control modes, such as direct internal and external pilot control. This configuration also provides flexibility in uploading several RPA types to the system. The file system is structured the way that special files can be up or downloaded from a remote server. So the software configuration is configurable in a flexible way and the flight data is obtainable from the remote. The simulator training for RPA pilots this way can be conducted in a virtual airspace without the need for the presence of an instructor. The RPA simulator training is also supported by a training syllabus with comprehensive training material and a multimedia interactive handbook.

During standardized flight missions on a simulator we have measured the pulse variability in medium frequency domain in order to characterize the psychosomatic stress level and its alteration in critical phases of flight. In the final protocol specific tasks (take off and landings, en-route flight) were measured, giving a profile about the undulation of stress level and responsiveness, providing an impression about psychic stability. We have measured the performance of:

(a) Real UAV operators with operational experiences
(b) Rotary wing pilots from an Air Force Base in Hungary
(c) Young students from secondary school (experienced in video simulator games such as car race games)

The other main direction for our HF research was practical training. Among limited financial conditions efficiency is always a keyword when expensive technical systems like UAS are operated. So as to replace a part of the practical flight training by a zero risk simulator training seems to be the perfect solution for risk mitigation. Using this notion, our team worked out a simulator training syllabus and of course an exact evaluation system for UAV pilots. The job was difficult because at the beginning we did not possess any accurate measuring methods for the assessment of the candidates' performance. Once they were in place, the results became comparable while the training minima and optima definable. During our simulations we use a control group for the selection and training processes' test. There were some debates among our experts about the composition of the experimental subjects' group. Some advised that only pilots from different branches should be tested once the group decided to consider UAV pilot as conventional pilots. Others insisted on using air traffic controllers since their competencies' overlapping with other aviation professionals. Finally, a decision was made on having both pilots and ex-pilots with different backgrounds, and flight traffic controllers and aircraft modelers included. Later, we enlarged the control group with computer fan teenagers.

4 Pulse Variability Measurements to Assess Psychosomatic Stress Level During Simulated Flights

By definition the UAV (Unmanned Aerial Vehicle) or RPA (Remotely Piloted Aircraft) is not under the personal control of the pilot onboard, but regarding as a complex combat flight system the responsibility of the operator in the ground based control station is crucial. The process of medical screening of operators should be similar to the selection of pilot candidates, but surely less expensive: the narrowed spectrum of medical examination (e.g. no sense to perform barochamber and centrifuge training), the extended utilization of flight simulators contribute to the overall economic application of UAV systems. Instead of threats posed by classic aero-medical stressors (hypoxia or G overloads) the main problem is loss of spatial orientation regarding UAV position and attitude. In order to avoid loss of Situational Awareness, a high level of mental and sensorial performance is a must. From flight safety aspect the sudden incapacitation could commence at the UAV operators most likely as a mental breakdown or frozen mental state which could lead easily to the loss of the “Big Picture”. The American Aerospace Medical Association, recently focused on human factor problems of UAV operators [1].

At each subject we monitored the (instantaneous) heart rate in experimental settings using ECG-like electrodes and recorded the beat-to-beat (RR) heart cycles by ISAX (Integrated System for Ambulatory Cardio-Respiratory Data Acquisition and Spectral Analysis, prototype 5.0) [2]. The quasi-periodic changes in electro mechanic cycles of heart summarized in a specific way (super positioning) resulting in variability. In short periods (second and minute ranges) these undulations can be divided in 3 main domains using mathematical models [3, 4]. These fluctuations in high frequency domain related to respiration, but in medium frequency domain (around 0.1 Hz) the increased rigidity (lowered fluctuations) is a consequence of vegetative imbalance, increased stress even for mental workload [5]. It is also stated, that after the suppression of oscillation there might be a rebound, which magnitude is proportional to the previous workload. For longer continuous workload the suppression undulation in time elapsed (deviation) is proportional to the workload [6]. We have examined the intensity changes in Medium Frequency domain (P_MF spectral or Power average) at rest and during different phases of simulated flight in similar and comparable time-periods, calculated the deviations before, during and after the flight. The raw files (containing RR beat-to-beat interval data) were saved on laptop, later on transformed into *psd* files. Based on log markers the comparable periods were identified and analyzing software fast Fourier transformation was executed, screening out the oscillation in high frequency domain.

The P_MF power as the marker of vegetative imbalance was demonstrated together with RR (cycle-length) and RR deviation trends. The "out" text file with parameters and the flight graph as the visual history are combined in one *png* file and archived by Paint software. At the different flight phases—independently from group categories—there were significant differences in implementing time periods (defining airspeed, approaching altitude, and attitude), so the time domain normalization was not achievable. Especially at landing tasks (repeated 10 times) the average heart rate is higher, than at take-off procedures—referring to increased vegetative sympathetic tone (Figs. 1 and 2). During focusing the attention the spectral power in middle frequency decreases, than slight rebound occurs: further oscillation is parallel with continuous vegetative tone modification.

The partition of en-route flight path is more difficult, so the exact identification of flight phases is not ready. (Specific integral software is necessary to calculate the area below the pulse and MF curves.) Retrospectively, the mental workload, the tenacity (focusing attention) and the low level of P_MF (rigidity) is noticeable; especially at approach and landing phase (Fig. 3).

Comparing to the resting phase the RR cycle change (the reciprocal changes of pulse) is similar in each group, that is the pulse increases, most explicitly during landing procedure (Fig. 4). The RR interval deviation at professional aviators increased, at the control students depressed (Fig. 5).

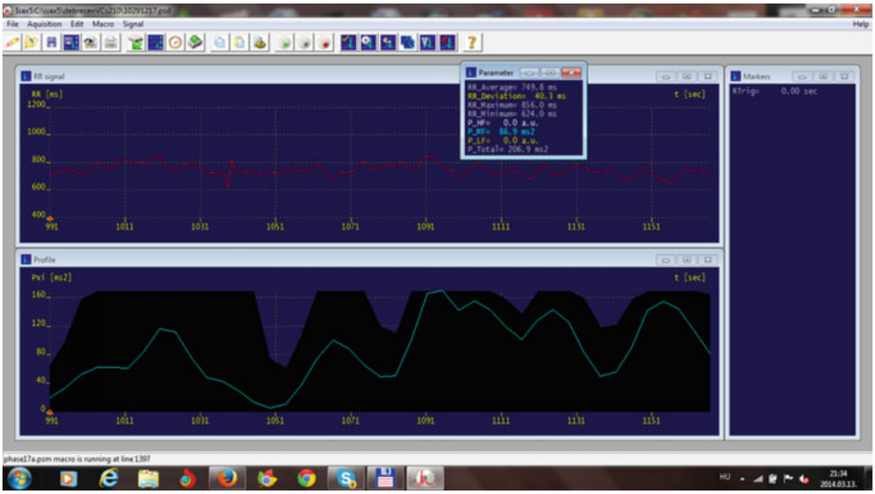


Fig. 1 UAV operator 10 landing procedures (heart rate 78 bpm)

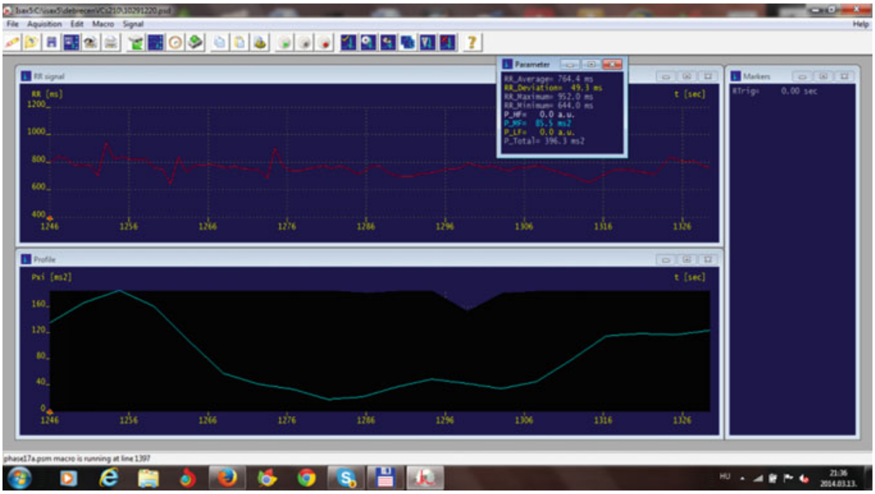


Fig. 2 UAV operator 10 take off procedures (heart rate 80 bpm)

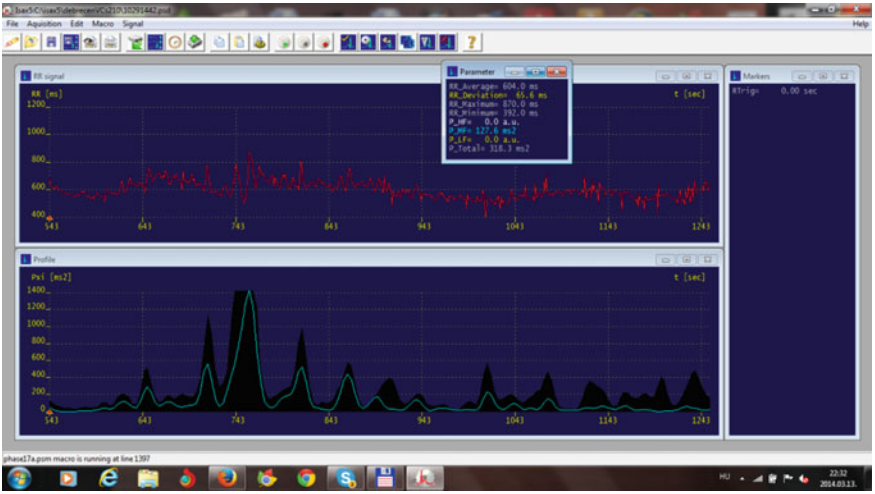


Fig. 3 UAV Operator (82 % performance) en-route flight (12 min)

Fig. 4 RR cycle changes during test flights

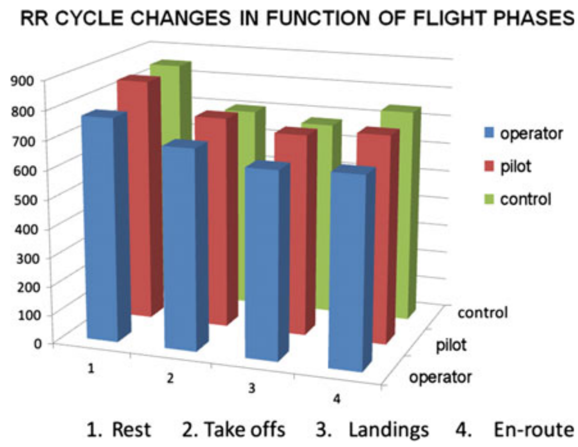
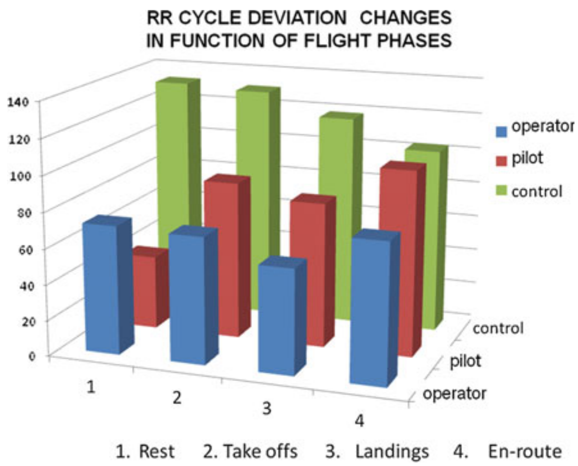


Fig. 5 RR cycle deviation changes during flights



5 Physical Requirements for UAV Crews

The practical side of the research is based on medical-diagnostic and performance-diagnostic test methods. Conducting the physical tests we aimed to introduce the basic methodology of the analyses, the research results of measurements and the conclusions drawn from the statistical analysis. Our inducing factors for the physical research were:

– The importance to measure the level of development of skills, such as fine-motor coordination, sensory-motor coordination. Adequate physical reflections of special uses should be measured, which is one of the goals of the research.

- We have experienced that in the assessment of both training and performance conditional skills outweigh coordination skills.
- Emphasis should be shown on the development of complex coordination skills, such as fine-motor coordination, arm-leg coordination and the adaptability of the vestibular system.
- Measuring sensory-motor coordination; sense of balance, spatial and orientation skills; improving the capacity of the vestibular system; fine-motor coordination; reaction and movement time; coordination of the senses and the limbs.

Controlling UAV devices belongs to a moderate load zone based on physical activity (the type of muscle activity, energy consumption). During a UAV mission the human body is exposed to substantial nervous-mental load, which has significant influence on the efficiency of the activity. Senses (receptors) are heavily strained as well. Physical and nervous-mental load incurred by these activities predictably reduce ability to work. Professional work ability is likely to be closely related to the individual's physical state (physical preparedness). Therefore, developing and maintaining endurance is a primary part of the crew's physical training. As a result of current scientific research, other factors needed to improve the training will be apparent. A specific feature of the research allows us to measure the impacts of the conditional state when carrying out the activities. Thus, it makes the training of the crew more targeted and effective and aids in recruitment for this kind of job. According to one of our main tasks, performance structure has to be measureable from a professional, physiological and conditional perspective. In this phase of the research the conditional side is a priority. However, it can only be defined if the other components of the structure are known.

Research aimed to eliminate deficiencies in the experiment by:

1. Conducting a cross-sectional study is with a control group.
2. Using the same at each recording subjects.
3. In the final data processing only individuals with complete profiles were processed.
4. The conditions regarding the environment, the facilities, the equipment and their state were the same.

Teams involved in the research:

1. Examined group	50 pilots at Szolnok Helicopter Base, Hungarian Defense Force, students in the NFTC program
2. 12 UAV operator	Military/Soldiers
3. Control group	12 officer candidates, students at NUPS and secondary school students in Szolnok

Table 1 Research test exercises [6]

Dimension	Factor	Assigned test exercise
Cardiorespiratory endurance	Cardiorespiratory endurance	Cooper 12-min run test
Power	Static strength	Hand grip strength
	Explosive power	Standing long jump
Muscle strength	Functional arm strength	Bent-arm hang
	Trunk strength	Sit-up
Speed	Running speed	10×5 m shuttle run test
	Speed of limb movement	Plate tapping
Joint mobility	Joint mobility	Sit-and-reach
Balance	Total body balance test	Flamingo test

6 The Mathematical-Statistical Methods of Data Processing

The data analysis was conducted regarding the age, background, former flying experience, and general aviation knowledge of the participants. It is probable that the correlation among these features can lead to a conclusion of the best, the most capable, and trainable source of future UAV pilots.

Our analysis involved the followings:

- calculating the mean of the measured data
- calculating standard deviation of the average
- calculating standard deviation
- calculating the coefficient of variation
- correlation calculation
- calculating confidence interval, significance

Based on the analysis, the tests connected to the research topic have been com-piled, which can be seen in Table 1.

7 Findings on Aeromedical and Physical Tests

During the aeromedical and physical tests the research concluded on the following statements below:

- The stress level change in vegetative nervous system and pulse rate variability as an adaptive response is widely studied. This presented experimental setting is not for cardiologic purpose, only to reify the continuous changes in vegetative nervous system during stressful simulated military flight task. Due to the low case number we analyze only trends, our preliminary data are not sufficient to state any finite correlation with performance (flying success rate). The mental

workload is accompanied by pulse rate increase at each group (as a tendency it was enhanced during landing procedure rather than take-offs). The pulse rate deviation increases at professional groups mirroring the psychic adaptation, while at students falls at complex tasks requiring constant attention.
- This research method belongs to the promising neuropsychology subject. Might be a useful tool to visualize the shifts in vegetative tone during mental workload. We should reach a full integration of time-frames (partition of pi-lot work into flight phases) with synchronized real time (quasi real time) data processing. After this standardization this model can contribute to the complex evaluation of operator's performance.
- The study of relationship between anthropometric features, the circulatory system, the conditional skills and complex skills gave results corresponding to the relevant literature.
- The significant relations between the measured parameters—particularly the conditional-coordination skills—suggest that relations between general health, the level of skills and performance grow stronger and deeper with age.
- Similarly to anthropometric indicators, indicators of the circular system show that the tested groups generated similar results to those who do not exercise regularly. The measured parameters show that 19 % of the research subjects have increased resting heart rate and high blood pressure.
- According to the Cooper test, the level of endurance is satisfactory, on the whole. However, in the evaluation of the test we have to bear it in mind that it compares performance to that of an average man. The expectations toward the tested groups are much higher than the average level of skills. From this perspective, their performance is rather poor.

8 Conclusion

UAV's application is no longer marginal within the aviation system, since recently, they are used in numerous fields and in various ways. The quick proliferation of remotely piloted vehicles raises many questions as to the methods of integration or flight safety before their integration. While the UAV itself is getting more and more sophisticated and reliable as a machine. The human factor, the operator, has received far less attention. The research discussed herein puts the human element into focus. Besides the theoretical and practical training issues, which have been studied but not displayed in this publication, we attempted to outline some core factors of UAV HF, for example, the physical or psychical suitability for the job. The data obtained from the simulator and tests will induce further studies on aeromedical or physical selection of future UAV crew members.

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References

1. Farley, R., Heupel, K., Lee, K., Gardetto, P., Johnson, B.: Human factors in remotely piloted aircraft (RPA). HQ AFSC/SEHI DSN 246-0880, ASMA Annual Conference (Phoenix, Arizona) (2010). www.asma.org. Retrieved 06 Dec 2010
2. Lang, E., Horvath, G.: Integrated system for ambulatory cardio-respiratory data acquisition and spectral analysis (ISAX). User's Manual, Budapest, Hungary (1994)
3. Sayers, B.: Analysis of heart rate variability. Ergonomics **16**, 17–32 (1973)
4. Akselrod, S., et al.: Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. Science **213**, 220–223 (1981)
5. Mulder, G., Mulder-Hajonides Van Der Meulen, W.R.E.H.: Mental load and the measurement of heart rate variability. Ergonomics **16**, 69–83 (1973)
6. Izso, L.: Developing evaluation methodologies for human-computer interaction, Chap. 4, p. 88. Delft University Press, Delft, The Netherlands (2001)