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ERGODESIGN FACTOR IN THE DEVELOPMENT OF UNMANNED AIRCRAFT SYSTEMS

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Abstract

Purpose: *the article deals with unmanned aircraft system (UAS) ergodesign issues related to their analysis, development, and evaluation, the main UAS ergodesign characteristics from the standpoint of ergodesign support for their development and operation.* ***Methods:*** *analytical and comparative.* ***Result:*** *UAS design is a technical and procedural complex with an anthropocentric orientation and connections. Their structure contains the actual design of the subject system and the description of interaction procedures with it. The essence and peculiarity of a system object ergodesign process is the design of not only subject but also the procedural composition of the system. It is singled out the basic principles of UAS design – it is the anthropocentric orientation of its component design options based on the operators` activity system analysis and the organization of subject environment for UAS components relying on functional comfort.* ***Discussion:*** *analysis, evaluation, development, and decision-making processes are based not only on quantitative characteristics but also on factors that cannot always be quantitatively measured (psychological, aesthetic, etc.). In some cases, at the first stage of UAS ergodesign, during the evaluation, when rigorous mathematical methods (algorithms and formulae) cannot be applied, it is necessary to rely on experts` professional judgments provided that these judgments are based on specially designed and formalized procedures. Further UAS ergodesign stages will be discussed in the following articles.*

Keywords: analysis; development; ergodesign; ergodesign requirements; ergonomics; evaluation; indicators; unmanned aircraft system

1. Introduction

The issue of the widespread use of unmanned aircraft (UA) is rapidly becoming relevant in Ukraine in light of global trends in aviation development in general.

It is known that the unmanned aircraft itself cannot perform its functions in isolation, except for so-called automatic ones. And even automatic UA at the time of activation require ground (basic) servicing implying the existence of a system called " unmanned aircraft system " (UAS). Its composition is discussed below.

In general, the purpose of UAS operation is to ensure a safe flight of a remotely piloted vehicle in the designated airspace for some aerial application. In doing so, UASs must operate in accordance with the ICAO standards intended for manned aircraft and other special standards reflecting differences in operational and legal aspects as well as flight safety aspects concerning manned-unmanned interaction.

In order to ensure UAS integration into the use of the designated airspace, a remote pilot responsible for a UA flight is required. Even if the autopilot is used to help it perform its functions, the responsibility of a remote pilot is not going to be fully shifted on technical means in the near future. Therefore, the ergonomic and ergodesign aspects of UAS development are one of the key factors in their effective use. Unfortunately, such aspects are quite fully developed only for manned aviation systems and are extremely insufficient for UASs.

2. Analysis of the latest research and publications

The analysis of UAS developments in recent years [1, 2, 3, 10], the results of the research carried out by the authors [4 - 7], reveal a strong tendency to increase the size and weight of drones, their variety and intended purpose (although, there is definitely a reverse trend towards miniaturization.)

From the standpoint of ergodesign support for the development and operation of drones as a part of the UAS, it is advisable to identify two main components:

- **unmanned aircraft (UA):** power plants; glider; onboard radio command system; on-board telemetry system; on-board navigation system; air signal receiving system; on-board power system; UA control system; autopilot; other vital UA systems; UA payload;

- **ground control station** (GCS): remote pilot's workstation (WS); payload operator`s workstation; remote pilot`s post; payload control system; ground radio command system for UA control; ground telemetry system; remote pilot`s video communication system; remote pilot`s radio communication system; starting and reload system of a UA status in flight; parachute UA air delivery system; UA storage and transportation system; UA target data terminal; ground control station tracking antenna; ground control station power supply system; UA automatic landing system.

It is known that the basis of UA compliance with its route is its flight according to a pre-designed plan based on line segments connected through points that are referred to as waypoints (WP). It ensures the correspondence between the task of performing patrol, surveillance or other aviation works (which are route in nature) over objects and the actual UA position in the air above an object.

An unmanned GCS has to provide the effective remote control of an aircraft in the first place. The automatic control system in it is only a desirable option, but not the main one. However, the practice of modern unmanned flights indicates that their "manual" piloting for a long time (5-10 hours) is associated with excessive remote pilots` workload. Therefore, as in manned aviation, there is a clear need for further UA piloting process automation.

The control system allows UA operation according to instrument flight rules and to some extent under visual flight rules. For this purpose, automatic, semi-automatic and manual modes are used.

In the *automatic* mode, flights are performed according to a pre-compiled plan with WPs beyond optical visibility. Flight control is exercised via a two-way telemetry line with the image of a terrain map on a remote pilot's monitor.

In the *semi-automatic mode*, waypoint target values are reached by a remote pilot.

From the ergodesign perspective, the main UAS component is a remote pilot's station. It consists of a remote pilot`s control unit (CU), a remote pilot`s PC desktop, a desk chair, a remote pilot`s PC system unit, flight information monitors, a light indication unit, a dual-engine control unit, a manipulator, a keyboard, a remote pilot`s computer, and an UA control stick.

In some cases, "*manual*" UA piloting can be applied within the scope of optical visibility according to the "see a UA from the side" method when an onboard controller is switched off. Command signals are sent via an additional radio command line.

Existing workstation developments essentially consist of a set of tools to ensure UA flight control. However, the studies [4, 6] conducted at National Aviation University with the authors` involvement have shown that:

- one monitor at a workstation is not enough;
- the use of manipulators such as a mouse makes a remote pilot`s job more difficult;
- remote pilot's station parameters in a sitting position at the desk should be regulated;
- adequate indication of the status of vital UA systems has to be provided.

In this regard, a new composition of a remote pilot's station without the shortcomings noted above is necessary. At such workstations, remote pilots can work without being tired for a long time. The UA workstation organization should also allow to quickly obtain the required flight information and information regarding the UA technical status. In addition, it is advisable to use a trackball manipulator instead of a traditional mouse. It makes it easier to operate the computer equipment with a remote pilot`s left hand since the right hand is usually busy controlling a UA.

The final functional UAS composition must also meet the requirements mandatory for Ukrainian civil aviation enterprises.

3. Aim of the research

To investigate the issues of the UAS design and operation ergodesign support, to determine the basic principles, stages, and procedures of UAS ergodesign development as a technical and procedural complex with an anthropocentric orientation.

4. Research results

Ergodesign support for UAS design according to its components must be based on the importance and sequence of the main design stages. Therefore, the result of ergodesign activity realization in the field of UAS development is the project for a technical-procedural complex showing anthropocentric characteristics and connections, the structure of which contains the actual UAS project and the description of its controlling procedures (interaction with them). All together, they form the ergodesign model of a technical-procedural system. The functional content of the model should be the hierarchy of links "field of activity – functional area – the role of an operator – workstation – algorithm of activity – equipment", and the subject representation of the UAS – system "AU – GCS – WS" functional content. From the anthropocentric standpoint, by the ergo-designer development of the model the organization of the following activity is ensured: "operator`s behavior – justification of the activity algorithm – WS development". In general, the ergodesign development of the UAS technical-procedural system should reflect the activity method used in the ergodesign model.

While maintaining a single algorithmic basis, the design synthesis process in the ergodesign of such complex systems as UASs is significantly different from a conventional ergodesign synthesis, although it contains a number of its procedures. The main essence of the system object ergodesign process is to provide a much greater number of the complex and diverse internal and external links between a technical procedural system and an operator than in case of designing an individual object directly connected with the operator. The main feature of the ergodesign, in particular of UASs, is the design of not only subject but also the procedural component of the system. Therefore, it is advisable to use the systematic approach in UAS ergodesign development. Understanding an object as a system allows developing an extensive strategy for its formation. The peculiarity of ergodesign methodology in this aspect lies in the focus on the integrity of the object and its determining factors. It enables to discover all the diversity and complexity of interconnections inherent in UASs and to present them in real time. Therefore, not only the comprehensive development of a wide range of specific problems but also the anthropocentric orientation of design solutions is the main feature of a systematic ergodesign development. The design of individual UAS components and systems should be carried out taking into account the maximum number of operators` requirements. It ultimately leads to the creation of a holistic system of the subject composition of the elements of a specific human activity environment (in particular - the ability to satisfy the requirements to functional comfort for all participants involved in UAS control and servicing processes). Based on the fact that the subject of ergodesign development is both the object and the process, in UAS ergodesign development it is distinguished subject and activity levels. Depending on the priority of utility, beauty or convenience issues in this process, it is predominantly determined its utilitarian, aesthetic or ergonomic aspects. A typological matrix of the UAS design is formed when these levels and aspects are combined.

As the ergodesign practice shows, for UAS ergodesign development, the activity level and, accordingly, the activity approach are necessary (and usually sufficient). It greatly simplifies a specific design process. Namely, it allows to solve the problem of matching the mental, physical and psycho-physiological capabilities of the operator with UAS properties creating in such a way the conditions for ensuring the operator`s optimal functional state in the process of their activity - the state of functional comfort. In terms of the activity approach, in the human-machine complex, technology as a means involved in human activities is treated through the prism of a human factor. In this regard, the ergodesign focus should be on the structure of activities and direct actions that have their functions determining the operation of the system as a whole. This approach makes it possible to obtain the integrated characteristics of remote pilots and UAS systems which are manifested in the specific conditions of their interaction and to ensure the fact that in systems "human – technology – environment" the requirements to take the human factor into account are considered. In accordance with the general ergodesign rules, developing a specific activity type and ensuring its optimization involves determining the requirements for internal means of activity.

Analyzing UAS systems, they include first of all the experience, knowledge, abilities and skills of operators (both remote pilots and other specialists), their mental, psycho-physiological and personal characteristics.

Equally relevant is the ergodesign development of external means of activity, for example, displays devices and controls. They are of particular interest to ergodesign professionals. Their function is to create a high functional quality of external means of activity by bringing to conformity internal means of activity with their external analogues.

Another important factor is the cost of activity, the number of physiological and psychological resources ensuring that tasks are performed at a given level. By determining the price of the activity, you can predict the reliability degree of the entire UAS. In this case, reliability means the probability of the system to complete a task at a given time with acceptable accuracy and preserve its operating parameters.

UAS operators` capabilities are also crucial for the successful implementation of activity tasks. *In ergodesign development of unmanned aerial systems, it is advisable to consider certain abilities*, in particular, **professional suitability –** the presence in a person of the set of characteristics that determine the effectiveness of tasks in a specific professional activity, as well as **professional adaptation** - *the formation of relevant knowledge, skills, and competences that make it possible to work effectively in standard and emergency production situations* [8].

The adaptation process, in turn, needs to be optimized both by the parameters of the effective UAS functioning and according to the parameters of the maximum use of the person`s specific abilities in its operation system.

In the future, for project situation optimization, it is advisable to rely on a limited number of people – a certain contingent of UAS users characterized as optimal according to the range of physical, physiological, psycho-physiological, and anthropometric indicators, as well as the level of training and preparation.

The aforementioned proves that for UAS creation and efficient operation, the system-activity approach serves as universal and basic. It should be applied to the design of various UASs and their components implementing it based on the ergodesign principles of different levels that determine the specifics of the design and operation of the basic UAS systems.

The results of research carried out in recent years by the authors [4 - 6] enable us to arrive at the following conclusions.

The main feature of UAS system ergodesign development, along with the consideration of a wide range of economic, development, design and other aspects, is the anthropocentric orientation of project activities, with the analysis of UAS staff`s activity as its necessary basis. In this way, such a postulate as the requirement of "human factor consideration" in "remote pilot - UA" systems is explained.

And an integral measure of UAS ergodesign perfection is the achievement of functional comfort as a criterion for operators` optimal psycho-physiological state in the course of their work and for the adequacy of UAS components and elements with the person`s individual capabilities.

Let`s define several levels of ergodesign principles of UAS development and operation (depending on detalization, significance, etc.). The main ones are the following:

**- principles of operators` activity organization (fundamental)** – ensuring optimal psycho-physiological UAS staff`s workload, muscle strength, movements; correspondence between the range of tasks and operators` needs, versatility and flexibility, the variability of their positions and awareness levels, workstation maintainability and adaptability;

- principles of designing operators` workstation environment – compliance with the optimal task performance level by operators (primarily by remote pilots) and with the convenience level of conducting operations; ensuring working posture optimization, the regulation complexity of UAS elements, the ergonomic organization level of the main working surfaces, provision with additional elements to support body parts, etc .

- layout principles of the main UAS components – providing access for operators to service UAS elements, the formation of task forces, the optimal lighting level, access to cleaning, etc.

During UAS ergodesign development, it is also necessary to rely on the identification and organization of their components as a complete integrated system of "human – UA – environment", with a remote pilot as the main dominator and component.

The basic UAS design principles are implemented by adherence to the lower level principles, the importance of which is determined by the specificity of each particular UAS type at each stage of their development.

Let`s identify the main stages and their sequence.

The initial stage of UAS development should be the ergodesign analysis of prototypes. UASs are not mass industrial products. Usually, their production is small-scale or it can be even a single item. In this case, as the main measure to justify project operations for UAS development, the ergodesign evaluation of prototypes is of utmost importance.

Modern research of the systems and objects of different composition, content, and scope [9] allow us to identify three main approaches that can underlie the evaluation of complex systems:

- physicality;
- modeling ability;
- purposefulness.

However, analysis and evaluation processes should be based not only on quantitative characteristics but also on factors that do not always have quantitative dimensions (ergonomic, aesthetic, etc.). Therefore, decisions should be formed on the basis of two components of development and decision making: formal and creative [9].

It should be borne in mind that in many cases of UAS ergodesign analysis and evaluation the result is professional expert judgments. They should be relied upon, provided that these judgments are obtained through specially designed and formalized procedures [10].

Operators` activity in UAS object-spatial environment is usually subdivided into performed according to predetermined conditions and actions (that is, algorithm-driven), and carried out based on knowledge, skills, stereotypes, insightfulness formed by previous experience, that is, heuristic components. Generally, the algorithm-driven element is predominant. UAS personnel`s activities are also determined by the need to comply with the requirements of various regulatory documents which must be applied in aviation and strictly followed in the process of UAS analysis and evaluation (the operation of drones is completely governed by the aviation operation rules). Taking these factors into account, let us consider the problem of assessing the UAS ergonomic quality level.

Among the ergodesign characteristics of such complex objects, in terms of the "human factor" ergonomic characteristics are the most important.UAS ergodesign quality indicators are based on product ergonomic characteristics and operators` ergonomic properties. It is important not to lose sight of the fact that that these indicators in one way or another determine UAS technical parameters, but the "human factor" as their basis is embedded in the product design. Therefore, it is advisable to correlate them with the benchmark, ideal, ergodesign characteristics of the product. It allows to establish the ergonomic quality level revealed during the UAS ergodesign evaluation.

At the same time, in the process of UAS ergodesign development, the main attention should be paid not to individual indicators, but to their structure, connections and to finding common formal properties between them reflecting the essence of such indicator interconnections. After all, UAS development has to be carried out according to a single performance criterion linked to all lower-level indicators, with the help of which they are formed into a single system and in relation to which the role of each of them must be considered and evaluated.

The significance of each indicator (which is mainly determined by the expert method) in their overall range with respect to the UAS ergodesign level criterion is also important.

It is known that the general quality criteria of human-technical systems are accuracy, reliability, specified system performance, and the level of an operator`s fatigue in the system [4, 8].

In this case, ergodesign indicators and criteria can characterize the optimality degree of the “remote pilot - UA” system in a broad, comprehensive sense. Consideration should also be given to the fact that there is some dependence between the UAS ergodesign indicator optimum values and the system performance criteria to which this object applies.

The final determination of UAS effectiveness must be made according to the integral criterion. However, in many cases it is impossible. If the integral criterion cannot be applied, it is advisable to use separate criteria (indicators) which are determined by the expert methods as dominant.

The creation of new UASs should also be based on the results of *remote pilots` functional-algorithmic activity analysis*. The authors` experience shows that it is an effective means of identifying "weak" points in a specific operational process, in particular - redistribution of information flows in the UASs, etc.

In general, the procedure for analyzing the UAS ergo- quality level as the first (basic) stage of their development can be presented in the following sequence.

1. Based on the expert method of selection, according to specific evaluation tasks, the dominant UAS ergodesign criteria and their components are selected.

2. Using particular reference samples, it is determined the ergodesign parameters of UAS

components (size, location of controls, display devices, etc.).

3. Using instrumental methods, taking into account ergonomic recommendations and expert assessments, it is determined *functional dependence* between ergodesign criteria and parameters to find the *ergonomic level values* of UAS components (by individual parameters).

4. Relying on the analytical method, it is determined the interrelations of ergodesign parameters with each other and their relationships in general, primarily according to the ergonomic criteria.

5. Based on the data obtained using the expert methods, *UAS ergodesign evaluation* is carried out according to each selected criterion (for example, the quality of how controls are arranged – according to the remote pilot`s fatigue criterion).

However, the ergonomic level is usually determined by several ergonomic criteria. Their totality is determined by *the complex ergodesign criterion* corresponding to the UAS ergodesign level.

6. To find the complex criterion, the values of individual criteria are previously determined according to a number of ergonomic parameters. Next, the interdependence between the single criteria, the way they are expressed through one another, and equivalent values between them within the complex ergonomic criterion are identified. The basis of the quantitative correlation between the single criteria is that, for example, if the speed of the reading process increases, its accuracy decreases, etc. Thus, in order to make an evaluation by the complex criterion, it is necessary to combine the values of the individual ergodesign criteria with the weight of each of them according to specifically developed ergodesign procedures. Thus, the complex ergodesign criterion will express the maximum achievable ergonomic quality level for this UAS type, and its ergodesign indicators will be close to optimal.

Other stages of UAS design will be discussed in the following articles.

5. Conclusions

The material presented in the article reflects the impact of the two processes that are taking place today, literally right in front of our eyes. First of all, ergodesign is transformed into a separate industry and is widely respected in today's design and business environment as a powerful integrator of manufacturers and users' interests in quality improvement, the safety of products and their operation efficiency (one can go online, type the word "ergodesign" and make sure that Google will respond with hundreds of links. And secondly, it is even more rapid development of unmanned aircraft. Perform the above-described operation with the word "unmanned aircraft", the search engine will return thousands of links).

Thus, in today's socio-economic conditions, UAS creation is constantly developing, it is formed, established and, most importantly, it is based only on the authority of evidence-based knowledge. There is a need for original project UAS ergodesign studies with reliance on normalized indicators (new standards are required), and manufactured UA samples are essentially the prototypes of new models that should be created using ergonomics knowledge as a success factor in boosting the sales of products due to their improving competitiveness.

The subjective criterion of qualitative UAS ergodesign is the formation of a sense of functional comfort in operators, when, for example, the workstation is perceived as a system of functional and object-space means that create comfortable and safe conditions for work, and UA are equipped with sufficient technical means to perform appropriate operational processes. It is the approach to UAS design that is promoted by the authors as the most effective.

To sum up, UAS design is a new and advanced technology associated with the design and operation of high-quality and high-tech products, it is a new type of design activity in contrast to traditional ergonomic product design. In a broad sense, its purpose is to ensure UAS effectiveness in all application fields, which is achieved through the combination and synergy of such design and operation aspects as the convenience, safety, comfort and aesthetic perfection of facilities and operating conditions for operators.

Some steps in this direction have already been made, in particular, based on the authors` research results, the draft national standards required for the UAS evaluation and examination such as “Design and ergonomics. Unmanned aircraft systems. Quality Indicator Nomenclature” and “Design and Ergonomics. UA remote pilots` workstations. The Nomenclature of Quality Indicators” have been developed and submitted for UAS state registration. The next step is «Design and ergonomics. Unmanned aircraft systems. Rules for quality level assessment”.

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Чинник ергодизайну в розробленні комплексів безпілотних повітряних суден

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Мета: у статті розглянуто питання ергодизайну комплексів безпілотних повітряних суден (КБПС), пов’язані з їхнім аналізуванням, проектуванням й оцінюванням, основні ергодизайнерські характеристики КБПС з позицій ергодизайнерського забезпечення проектування й експлуатації. **Методи:** аналітичний, порівняльний. **Результат:** проектування КБПС – це технічно-процесуальний комплекс, що має людиноцентричну спрямованість і зв'язки, структура яких містить власне проект предметної системи та опис процедур взаємодії з нею. Головний зміст і особливість процесу ергодизайну системного об’єкту – це проектування не тільки предметного, але й процесуального складу системи. Основні принципи проектування КБПС – антропоцентриська орієнтованість проектних вирішень їх елементів на основі системного аналізу діяльності операторів та організація предметного простору складових КБПС з позиції функційного комфорту. **Обговорення:** процеси аналізування, оцінювання, вироблення та прийняття рішень базуються не тільки на кількісних характеристиках, але й на чинниках, що не завжди мають кількісні виміри (психологічні, естетичні тощо). У певних ситуаціях на першому етапі ергодизайнерського проектування КБПС – оцінюванні, – у разі неможливості використання строгих математичних методів (алгоритмів, формул) треба покладатися на судження фахівців-експертів за умови, що ці судження отримані за допомогою спеціально розроблених і формалізованих процедур. Подальші етапи ергодизайну КБПС буде розглянуто у наступних статтях.

Ключові слова: аналізування, ергодизайн, ергодизайнерські вимоги, ергономіка, комплекс безпілотного повітряного судна, показники оцінювання, проектування

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Фактор эргодизайна в разработке комплексов беспилотных воздушных судов

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Цель: в статье рассмотрены вопросы эргодизайна комплексов беспилотных воздушных судов (КБПС), связанные с их анализом, проектированием и оценкой, основные эргодизайнерськие характеристики КБПС с позиций эргодизайнерського обеспечения проектирования и эксплуатации. **Методы:** аналитический, сравнительный. **Результат:** проектирование КБПС – это техническо-процессуальный комплекс, имеющий человекоцентрическую направленность и связи, структура которых содержит собственно проект предметной системы и описание процедур взаимодействия с ней. Главный смысл и особенность процесса эргодизайна системного объекта – это проектирование не только предметного, но и процессуального состава системы. Основные принципы проектирования КБВС – антропоцентрическая ориентированность проектных решений их элементов на основе системного анализа деятельности операторов и организация предметного пространства составляющих КБВС с позиции функционального комфорта. **Обсуждение:** процессы анализа, оценки, выработки и принятия решений базируются не только на количественных характеристиках, но и на факторах, не всегда имеющих количественные измерения (психологические, эстетические и т.п.). В определённых ситуациях на первом этапе эргодизайнерского проектирования КБПС – оценивании, – в случае невозможности использования строгих математических методов (алгоритмов, формул) следует полагаться на суждения специалистов-экспертов при условии, что эти суждения получены с помощью специально разработанных и формализованных процедур. Дальнейшие этапы эргодизайна КБПС будут рассмотрены в следующих статьях.

Ключевые слова: анализ, комплекс беспилотного воздушного судна, показатели оценивания, проектирование, эргодизайн, эргодизайнерские требования, эргономика

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