ERGODESIGN ASPECTS OF THE DEVELOPMENT OF UNMANNED AERIAL VEHICLE SYSTEM

Kardash O. https://orcid.org/0000-0002-8497-3453[1], https://orcid.org/0000-0002-8497-3453
Rubtsov A. https://orcid.org/0000-0002-7992-8236[2],
Svirko V. https://orcid.org/0000-0002-6482-6827[3]

[1] Doctor of engineering sciences from technical aesthetics a professor is a design department Institute of arts kyiv borys grinchenko university 02154, Ukraine, м.Київ, boulevard I. Shamo, 18/2 kardash.o.v@ukr.net
[2] Senior Researcher The Research Part of the National Aviation University 03058, Ukraine, Kyiv, 1, Liubomyra Huzara ave., building 9
[3] Cand. of psychol. Sciences Director the Ukrainian Research Institute of Design and Ergonomics of the National Aviation University 03058, Ukraine, Kyiv, 1, Liubomyra Huzara ave., building 9

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Abstract. The analysis of the problems of development and use of unmanned aerial vehicle systems (UAVSs) indicates the need to reconsider the role of the human factor in their operation. It is primarily due to the latest UAVS design technologies and new approaches to their use. Such analysis becomes dominant in addressing the safety, efficiency and comfort of “human-unmanned aerial vehicle” system components, in particular control subsystems. The author`s research results underlying the present article indicate the need for qualitatively new methodology and techniques for UAVS ergodesign development and operation, first of all, for their evaluation, drawing up appropriate methodology documentation and, most importantly, the formation of the complex of UAVS ergodesign quality indicators with their subsequent standardization. The subjective criterion of high-quality UAVS ergodesign is the formation in remote pilots and other operators a sense of functional comfort, when a workstation is perceived as a system of functional and objective-spatial means that create acceptable and safe working conditions and a UAVS is equipped with sufficient technical means to execute the workflow. It is this approach to UAVS design that is promoted in this publication.
Keywords: ergodesign; unmanned aerial vehicle systems; system analysis; automated workplaces; ergodesign criteria, requirements, UAVS quality indicators.

Introduction

One of the main current trends in aviation development is the active formation of unmanned aerial vehicle systems (UAVS). Thus, at the beginning of this century, about 150 UAVS types were developed and produced in the world, currently there are more than 1200 of such systems (Osipov, 2011). This growth and diversity is attributed to the wide range of UAVS applications. For example, for the Ukrainian start-up AVISION Robotics created in 2014, there are no restrictions on the number of controlled UAVs and their routes. A large number of drones can operate both in the city and in the field: all routes can be calculated and adjusted automatically (Kulakov, 2017).

Currently this Ukrainian team together with Amazon, Verizon and other companies is working on the NASA team to develop common standards, as well as protocols for UAV control and monitoring. These trends were confirmed by the 6th International Aerospace Industry Exhibition "Singapore Airshow" which took place in 2018 in Singapore (Levchuk, 2018).

The International Civil Aviation Organization (ICAO) considering the UAVS issue highlights the key points characterizing these systems. In particular, in order to distinguish the job title of unmanned aerial vehicle (UAV) pilots who perform their duties related to UAV piloting outside the aircraft, it is proposed to use the term "external pilot" (instead of the term " system operator pilot "proposed in ICAO Circular 328-AN / 190 "Unmanned Aircraft Systems" (ICAO, 2011)).

In our opinion, a more precise definition is given in the Air Code of Ukraine (VVR, 2011). It is a "remote pilot". We will use it further implying that other UAVS operation functions during flight are performed by "operators".

In science, unmanned aerial vehicle systems are used to obtain a variety of new knowledge. The UAVS application scope has two main areas – military and civil. Military UAVSs in accordance with the functional purpose can be used as surveillance (in particular, to regulate fire on the battlefield), reconnaissance, attack ones, etc.

The UAV civil application is much broader and extremely diversified: from agriculture and construction to oil and gas and security sectors. From the ergodesign point of view, it is important that the vast majority of crashes (or "flight accidents" according to the terminology used in civil aviation) at such sites occur due to insufficient adaptation of UAVS elements to operating personnel`s capabilities and needs. Therefore, taking into account the human factor is crucial in creating such systems, and the role of ergodesign as a scientific and practical discipline evaluating and studying the impact of the human factor is dominant in modern UAVS development.

The consideration of UAVSs – complex multilevel systems – as an object of ergodesign determines the use of the system approach as the most effective tool of their formation. Therefore, the ergodesign studies of UAVSs and their individual subsystems (unmanned aerial vehicles, ground control stations, launching and landing aids, etc.) should be based on the anthropometric, functional, psycho-physiological, macro- and microanalysis of real UAVSs.

Since in this case the system is the highest form of organization, in general, a UAVSshould be considered as a complex of necessary and sufficient elements that are in a stable correlation and interaction within relatively defined limits and form a single whole.

The main ergodesign objective in this regard is to ensure the efficiency, safety and comfort of UAVS management, repair and maintenance. Therefore, the relevance of such studies is out of question and is growing every year, because their subject is the development and justification of ergodesign principles, the requirements and methods of creating and operating effective UAVSs.

The principles of the system approach are quite thoroughly addressed in literature sources (VNIITE, 1983; Balashov, 1985). Most authors agree that a characteristic feature of the system design process is a sequence of approximations to the optimal solution. Obviously, the reduction in the number of sequential actions also characterizes the optimization degree of the UAVS ergodesign development process in the context of their creation.

We focus only on the main aspects of ergodesign development of such objects, namely, on operators and UAVS remote pilots` activities. Numerous operational stressors (unsatisfactory ergonomics of pilot stations, unacceptable temperature conditions, low level of information flow organization, etc.) have been established during the study of their working environment (Ouma et al., 2011; Thompson et al., 2006).

It has been proved (Chappelle et al., 2011) that the main factors of UAVS operators` professional stress are also the lack of specialists, variable work organization, too long work shifts, difficulties in perceiving the interface of used computers, etc. All this indicates the urgent need to determine the ergodesign quality indicators of UAVS components and the formation of ergodesign requirements for UAVS development and operation

1. Object and methods of study

In modern socio-economic conditions, design approaches to UAVS creation are constantly evolving, are being formed, and require focused ergodesign research centered around further development of the relevant regulatory framework based on their results. It should be borne in mind that new UAVS models should be created on the functional principle of designing processes, not products

After all, the subjective criterion for the UAVS quality from the standpoint of ergodesign is a sense of functional comfort, when their components are perceived as a system of functional and objective-spatial means that create comfortable and safe conditions for operators, and UAVS has sufficient technical means to carry out this activity.

The article proposes the approach to the UAVS creation according to which ergodesign is considered not only as a progressive technology for the creation and production of high quality science-intensive products but also as a research and development activity different from traditional product design. In a broad sense, the purpose of this approach is to ensure UAVS effectiveness in all application areas. It is achieved through synergy at all the stages of UAVS life cycle and, above all, of such aspects of the system as efficiency, safety, and comfort.

The first step in this direction – the identification of ergodesign quality indicators of the main UAVS components, primarily, of operators` automated workstations – has already been taken.

Thus, the aim of the paper is to study the role of the human factor in the UAVS creation and operation as well as to develop its ergodesign evaluation indicators.

The applied research methods include systematic ergodesign analysis of UAVS structural and functional components as well as the computer simulation of their operators` activity.

2. Presentation of results and discussion

From the standpoint of the ergodesign support of UAVS design and operation, in their composition typically composed of at least five components – unmanned aerial vehicle (UAV), ground control station (GCS), launching device, landing aids, antenna-rotary device – it is expedient to single out the following main components:

- UAV: a glider, an airborne control system, power plants and other life-critical systems;
- GCS: remote pilots (RP) and payload operators` workstations; control, telemetry, and radio communication systems, etc.

The ergodesign analysis of these components conducted by the authors revealed the following typical weak points inherent in the vast majority of UAVSs.

1. Extremely insufficient UAVS equipment with display devices adequate for operators` the activities.
2. Complicating the operating personnel`s work through the use in UAVS design of control effectors operating based on different principles.
3. Insufficiency (in some cases the absence) of the adjustable parameters of UAVS operators` main workstations.
4. Insufficiency and inconsistency (according to modality, the nature of information provision) of the status indication of life-critical UAVS systems, etc.

Even this far from being complete list of shortcomings indicates the need for the in-depth ergodesign research of each of UAVS components and further ergodesign support of their development and operation.

It should be borne in mind that the main feature of systematic ergodesign development is not only a comprehensive consideration of a wide range of specific problems but also the anthropocentric orientation of design actions. In particular, it is ensuring the ability to meet the requirements for the functional comfort of all participants in UAVS control and service. And the activity approach is a necessary feature of ergodesign development. In this way, such a postulate as "taking into account the human factor" can be most fully realized, in particular, in "remote pilot – UAV" subsystems.

As mentioned before, an integral measure of UAVS ergodesign perfection is the achievement of functional comfort as a criterion for operators` optimal intellectual and psychophysiological state in the process of their activities and as a criterion for the adequacy of UAVS components and elements for individual operators` capabilities. It is well-known that the general criteria and indicators of the quality of socio-technical systems are accuracy, reliability, productivity and operators` fatigue in a system.

Regarding UAVS ergodesign criteria, it is worth noting the following. In the ergodesign development, depending on priority given to the problems of utility, beauty or convenience, it is respectively determined their predominantly utilitarian, aesthetic or ergonomic aspect. The determining factor here is the level of activity, which significantly objectifies the specific UAVS design process. Their subsystems are considered as a means of ensuring human activity and are designed taking into account the human factor. In this case, the focus should be on the structure of operators` activities with all UAVS elements, and actions themselves are multi-component acts determining the operation of a system as a whole.

It should be borne in mind that ergodesign development is the initial stage of the UAVS life cycle, the results of which are crucial for the further functioning of a system and the implementation of project ergodesign activities results in a project of a technical and procedural complex containing psycho-physiological connections, UAVS personnel`s anthropometric features, etc. Their structure contains the actual project of a system and a description of its control procedures.

Taken together, they make up the UAVS ergodesign model. The functional content of such a model is a hierarchy of connections "functional area – an operator`s activity role (work algorithms) - workstations- equipment systems - equipment units". From an anthropocentric point of view, the ergodesign model determines, in particular, the activity structure and organization (its rationale, algorithms, etc.).

In general, the ergodesign of the UAVS technical-procedural system determines activities carried out in an ergodesign model. Such an approach requires a hierarchical construction of ergodesign support for UAVS development, when each of its "lower" levels is included as a subsystem in a "higher" level: an individual element is included in a complex, the complex becomes a part of a block, the block is integrated into a UAVS subsystem, etc.

In the UAVS ergodesign development process, one of the important principles is compliance with the complexity of individual indicators. For example, the quality of display devices is determined by a set of ergodesign indicators such as accuracy and the operator`s visual fatigue when analyzing readings. The set of individual ergodesign indicators determines the complex ergodesign indicator, which can almost completely show the ergodesign level of UAVS components.

The nature of UAVS operators` interaction necessitates the formation of the special indicators and criteria for the quality or efficiency of a system as a whole and its individual components. These criteria should evaluate both each element of a system and the system as a whole. It is also considered proven [7, 8] that the correctness of the general system efficiency determination depends on a number of individual (or internal) indicators characterizing the functioning of system elements.

But in case of UAVSs, the main attention should be focused not on individual indicators, but on their structure, interconnections and finding common formal properties – isomorphism reflecting the content of the interconnections of indicators. After all, ergodesign development should be carried out according to a single efficiency criterion to which other indicators are related and by which they are all directly or indirectly governed. Thus, all indicators should be grouped into a single system based on the efficiency criterion, and their role should be considered and evaluated according to this criterion.

In practice, based on specific tasks, the dominant ergodesign criterion is usually determined, such as functionality, reliability, speed, fatigue, etc. An important requirement for such a criterion is for it to have specific ergodesign content. The following should be taken into account. The nature of the criterion that affects the UAVS ergodesign level is not as important as its significance and weight in a number of other criteria and indicators. This weight should relate to the type of functional dependence of the UAVS ergodesign level on changes in this factor, although the dependence itself is determined by the nature of the current factor.

It should also be borne in mind that the typical ergodesign assumption about the approximation of indicators to the reference (ideal) ergodesign characteristics of the product is valid only to some extent, which is further defined as the level of ergodesign indicators and is detected during UAVS ergodesign development and analysis.

The basis for an objective assessment of a system and the determination of the the ergodesign level of UAVS quality is formed by the results of its functional analysis. At this stage, it is possible to make a comprehensive definition of quality but by one selected criterion only. Thus, one criterion can be used to assess, for example, an operator's seat, or an automated workstation as a whole based on the rate of human fatigue as the main ergonomics characteristic of an operator's seat.

It should be taken into account that among the ergodesign characteristics of objects of such complexity as an UAVS, the most important ones in terms of the "human factor" are its ergonomic characteristics. They underlie other UAVS ergodesign quality indicators determining the main technical parameters of this system. It should be clearly understood that indicators derived from the requirements of the "human factor" have to be "embedded" in the design of the product. Therefore, it is advisable to constantly correlate them with the reference or ideal ergodesign characteristics of the product. It makes it possible to determine the ergonomic level of quality manifested in the UAVS ergodesign development.

The creation of new unmanned aerial vehicle systems should also be based, first of all, on the results of the functional-algorithmic analysis of remote pilots` activities. The authors` experience shows that such an analysis is an effective way of identifying weak points in a particular operating procedure, for example, in the optimization of information flows in an UAVS, etc.

In general, the procedure for determining the required ergodesign level of UAVS quality as the initial stage of its design can be presented in the following sequence:

- based on specific tasks, it is chosen (usually by the expert method) the dominant ergodesign indicators of a developed UAVS and its components;
- following the analysis of reference samples, it is determined the ergodesign parameters of UAVS components (in particular, the parameters and location of workstations, controls, display devices, etc.);
- using instrumental methods and taking into account ergonomic recommendations and expert assessments, it is determined functional relationships between the ergodesign criteria and ergodesign indicators of system components, and it is evaluated the ergonomic level of UAVS components (based on individual parameters);
- establishment (usually according to the analytical method) of the interconnections of ergodesign indicators with each other and their relationships as a whole, primarily with ergonomic criteria;
- on the basis of the received data, it is carried out the ergodesign estimation of the developed UAVS according to each chosen criterion (for example, the rationality criterion – the arrangement of components or the remote pilot`s fatigue criterion). We emphasize once again that the UAVS ergodesign level is determined by several criteria. Their combination is determined by a complex ergodesign criterion which corresponds to the UAVS ergodesign level. To establish it, the values of individual criteria are determined according to a number of parameters and their interdependence is found as well as the equivalent values of individual criteria within the framework of the complex criterion. After all, the complex criterion must combine the values of individual ergodesign criteria taking into account the importance of each of them. This is done according to specially developed ergodesign procedures. The complex ergodesign criterion obtained in this way will express the maximum achievable ergodesign level of quality for the given UAVS type (or its individual component), and its ergodesign indicators will be close to optimal.

We emphasize that this is only the initial, basic stage of UAVS ergodesign development.

Further ergodesign support of UAVS development according to its stages should be based on the purpose and sequence of its main stages and be centered around the relevant ergodesign requirements and indicators.

Given the limited volume of the article, we present in tabular form a system of the ergodesign quality indicators of UAVS operator`s automated workstations (AW) (Table 1) and a system of the unified ergodesign indicators of UAVS ground control stations (GCS) (Table 2), as the main components of unmanned aerial vehicle systems with regard to the human factor.

Table 1. Ergodesign quality indicators of UAVS operator`s automated workstations (AW)

Complex indicator of the 2nd level	Individual indicator
Complex indicator of the 1st level Ease of AW use	
Rationality of the function allocation between the operator and technical equipment	The level of the optimal operator`s workload
	Rationality of the operator`s activity organization and algorithm
	The validity level of functions (actions) performed exclusively with operator`s approval
	The human resource reserve level (operator`s functions in case of a system failure)
Design operational comfort	The general adequacy of the AW sizes for the performed operating task: seated activity
	standing activity
	seated and standing activity
	The level of the provision of adjusting work surfaces in the AW design
	The level of provision in the AW design of the opportunity to control viewing distances
	Provision of the opportunity in the AW design to change look-out angles
	Provision of the visual markings of specific device groups (color, layout, etc.) in the AW design
	Availability in the AW design of an alarm of the control effector (CE) failure
	Availability in the AW design of an alarm of the visual information means (VIM) failure
	Compliance of work surfaces with ergonomic requirements for firmness, colour, and stiffness
	Availability in front of a display of a work surface for keeping records, keyboard and communication equipment placement, etc
	Compliance with ergonomic requirements for the lighting levels (natural, general, and spotlight) of the AW and its elements
Rationality of layout	Adequacy of the AW layout for the performed task
	Appropriateness of the AW operator `s main working posture for the activity structure
	Compliance of mutual arrangement of AW components with the activity requirements
	Correspondence between the CE and VIM mutual arrangement and the structure of the executed tasks
	Compliance with the ergonomic requirements for legroom organization when performing work in a sitting position
	Compliance of the visibility of AW components with ergonomic requirements
	Compliance of the CE and VIM mutual arrangement with ergonomic requirements
	Provision of distances recommended for simultaneous interaction with CEs in the layout of AW components
	Ensuring the functionality of CE and VIM clustering
	Ensuring the sufficient operator`s freedom of movement within an AW while performing work in a standing position
Correspondence between design and the operator`s anthropometric characteristics	Taking into account in the AW design of the size of the human body and its parts
	Taking into account in the AW design of the shape of the human body and its parts
	Correspondence between distances to control effectors and the operator`s anthropometric characteristics
	Correspondence between the form of EC gripping parts and the anthropometric features of the operator`s hands (legs) and character of gripping
The operator`s psycho-physiological load	Compliance of the principles behind the operator`s interaction with CEs and VIM applied in an AW with ergonomic requirements
	Correspondence between the level of accuracy of devices and the required accuracy of indicators
	The monotony level of the operator`s activities
	The level of the operator`s information load
	The level of the operator`s neuropsychological and emotional tension
	The level of ensuring the ability to perform operations with a coordinated system of movements
	The deviation level of the AW operator`s optimal movements from physiologically rational characteristics
Compliance with ergonomic requirements for the operator's fatigue level	The level of the AW operator`s static stress
	The level of a decrease in the operator`s emotional state while working at an AW
	The level of the deterioration of the operator`s functional state while working at an AW
	Provision of support for the operator`s elbows, arms, forearms, and back

Continuation of table 1

Complex indicator of the 1st level Ease of AW management and control (controllability)	
Complex indicator of the 2nd level	**Individual indicator**
Compliance with ergonomic requirements for control effectors (CEs)	Compliance of the principles behind the operator`s interaction with CEs with ergonomic requirements
	Compliance with ergonomic requirements for CEs used in an AW
	The unification level of the organization types and methods of CEs used in an AW
	Compliance with ergonomic requirements for CE coding means used in an AW
	Compliance with the ergonomic requirements for the effort required to activate CEs
	Adequacy of the CE form, sizes, and material for the actions they perform
	The level of ability to determine the state of the controlled object (process) according to the CE position (on-off)
	Compliance with ergonomic requirements for contrasts between CEs and AW surfaces
Compliance with ergonomic requirements for the CE placement	Adequacy of the CE placement for performed tasks
	Correspondence between the CE placement and the limits of reach of the operator`s motor field in a certain working posture
	Compliance with ergonomic requirements for ways to cluster several CEs into groups (panels)
	Correspondence between the mutual arrangement of panels and control effectors and the operator`s activity algorithm
Complex indicator of the 1st level Ease of AW management and control (controllability)	
Compliance with ergonomic requirements for visual information means (VIM)	Compliance with ergonomic requirements for visual information means used in an AW
	Adequacy of the VIM form and sizes for the actions they perform
	Compliance of AW information elements with ergonomic requirements for contrast, colour, and surface texture
	Compliance with ergonomic requirements for VIM visibility angles
	Compliance with ergonomic requirements for symbolic and graphic information used in an AW (texts, numbers, diagrams, tables, markings, signs, etc.)
	Compliance with ergonomic requirements for working with visual display units
	Adequacy of displays used in an AW for performed tasks
Compliance with ergonomic requirements for the VIM placement	Correspondence between the VIM placement and recommended visual observation zones
	Compliance with ergonomic requirements for the visibility of panels and an individual VIM
	Compliance with ergonomic requirements for VIM placement and their functional interaction with an operator
	Compliance of the brightness levels of VIM information items with ergonomic requirement
Compliance with ergonomic requirements for acoustic and tactile information	Correspondence between the nature of acoustic and tactile messages (simple, complex, periodic, continuous, etc.) and the algorithm of the operator's activity
	Correspondence between acoustic and tactile information media (tone, vibration, configuration, temperature, etc.) and the algorithm of the operator's activity
	Compliance with ergonomic requirements for coding of acoustic and tactile signals
	Compliance with ergonomic requirements for voice message indicator units
AW assimilation	Adequacy, stereotypy, and structural ordering of the information model
	Adequacy of information on AWs and controlled processes
	Redundancy of information on AWs and controlled processes
Compliance with ergonomic requirements for operational documentation	Compliance with ergonomic requirements for operational documentation
	Clarity of information presented in operational documentation
	Quality (clarity, scale, layout logic) of illustrations, schemes, and graphic elements in operational documentation
	Comprehensibility of operation manual for AW components
	Structuring and availability of additional information on AW operation
Compliance with ergonomic requirements for equipment and tools required for AW operation	The complexity of the algorithm for the maintenance and repair of AW components
	Ease of access to adjustable and replaceable elements
	Availability of technical failure diagnostics means
	Ease of use of instruments and controls and diagnostic equipment
	Provision of comfortable conditions for the repair and maintenance of AW components
	Accessibility of AW components during maintenance and cleaning
Compliance with ergonomic requirements for physical factors of the AW environment	Compliance with AW noise level standards
	Compliance with the standards of natural and artificial lighting of the GCS room, AW, CE and VIM work surfaces
	Compliance with the standards of AW mechanical vibrations
	Compliance with the standards of electromagnetic fields and static electricity in the AW environment
	Compliance with the standards of the AW thermal environment
	The level of AW protection against draught and dust

End of table 1

Complex indicator of the 1st level HYGIENE OF THE AW LOCATION ENVIRONMENT	
Complex indicator of the 2nd level	**Individual indicator**
Complex indicator of the 1 st level AW SEFETY	
Compliance with ergonomic requirements for chemical and biological AW environment factors	Compliance with ergonomic requirements for the concentration levels of hazardous substances in the air of the GCS room
	Compliance with ergonomic requirements for the presence of hazardous components in AW materials and coatings
	Compliance with ergonomic requirements for the concentration of microorganism (including fungi) in the air or on the surface of AW elements
	Adequacy of protective means against hazardous events in an AW
	The safety level of the factors of a mechanical, chemical, and electrical origin
	The level of protection against harmful radiation
	The level of protection against extreme temperatures
	Compliance with ergonomic requirements for audio alarm signals
	Compliance with the requirements for visual alarm signals
	The level of compliance with the conditions for the prevention of hazardous events when working with VIM
	The availability of tools and materials needed in hazardous situations at an AW
	The adequacy level of CE protection means
Complex indicator of the 1st level AW ARTISTIC EXPRESSION	
Decorative expression of the AW form	Correspondence between the AW artistic image and its purpose Correspondence between the AW artistic image and modern ideas about the products of a certain type
AW form originality	Originality of the used AW formation principles: plastic, compositional, layout Peculiarity of applied decorative and color-graphic elements Adequacy of originality methods for the expediency requirements
AW form fashionableness	Correspondence of the color-graphic solution, AW finishing to "fashionable" decorating methods Correspondence of AW compositional and plastic characteristics (or its packaging)to "fashionable" methods of form making
Decorative expression of the AW form	Decorative expression of the used materials and coverings Correspondence between the AW decorative expression methods and the expediency requirements
Stylistic unity of the AW form	Compatibility of AW design features with each other within the limits of a chosen style (level of eclecticism) Compatibility of AW design features with other components of a system within the limits of a chosen style
Complex indicator of the 1st level Rationality of the AW form	
Functional and constructive conditionality of the AW form	Adequacy of the AW form for its the purpose and operating conditions (for example, manual and portable AW) Adequacy of the AW form for its composition and layout scheme Suitability of the use of constructive methods of organizing the AW form elements
Technological conditionality of the AW form	Compliance of the AW form with the requirements of its manufacturing technology
Complex indicator of the 1st level INTEGRITY OF THE AWCOMPOSITIONAL-PLASTIC FORM SOLUTION	
Harmony of the AW three-dimensional structure	Interdependence of primary and secondary elements of the AW form in size, proportions and scale The degree of AW scale and its elements (visual matching to the size of the human body)
AW architectonic form	Manifestation in the form of the nature of AW structural loads Visual balance of the AW three-dimensional, compositional and plastic structure
Plasticity of the AW form	Integrity of three-dimensional and plastic solution of the AW form Correspondence between the volumetric and plastic solution and applied materials, and manufacturing technology
Artistic and graphic expression	Compositional validity of the arrangement of graphic elements on the AW parts The degree of conformity of the nature of the fonts to the semantic value of the inscriptions Expression of AW functional graphics
Color-graphic compatibility of elements	Interdependence between colour and graphic elements Subjection of colour and graphic elements to the general AW compositional and colour-graphic solution
Color and texture compatibility of elements	Compatibility of different types of materials, composition, textures, coatings used in the AW with each other Consistency of different types of materials, composition, textures, coatings with the AW shape, purpose, and operating conditions
Complex indicator of the 1st level PERFECTION OF PRODUCTION AND THE PRESERVATION OF THE AW MARKETABLE CONDITION	
Fineness of contours	Fineness of contours, fillets, and joints of the elements of the AW form
Quality of the AW surface treatment	Careful treatment of AW surfaces Careful application of decorative and protective coatings
Clarity of signs and accompanying documentation	Quality of AW graphic elements and promotional materials
Resistance to damage	Protection of the AW form elements and surfaces against damage, attrition, and decorative covering quality changes

Table 2. A system of the unified ergodesign indicators of UAVS ground control stations (GCS)

Group of indicators	Complex indicator of the 1st level	
	Complex indicator of the 2nd level	Individual indicator
Ergonomic indicators	**Ease of GCS use for its intended purpose**	
	Correspondence of GCS design and its elements to human anthropometric characteristics	Taking into account in the GCS design the size of the human body and its parts Taking into account in the GCS design the form of the human body and its parts
	The operator`s physical load (severity of work performed	Dynamic physical activity: the amount of work performed during the transportation of GCS, preparation for use, configuration, adjustment, assembly (disassembly); the mass of the GCS when it is moved Static physical activity (holding effort) Deviation of working posture and movements from physiologically rational characteristics
	The operator`s psycho-physiological load (work intensity)	The monotony level of the operator`s activity The operator`s information load Intellectual intensity of the operator` s activity Nervous and mental and emotional tension of the operator s activities
	Development of fatigue and a reduction in the operator`s functional state for a given time	The operator's energy consumption level The level of changes in the operator`s functional state The level of a decrease in the operator`s emotional state The level of reduction in motivation for work
Ergonomic indicators	**Ease of GCS management and control (controllability)**	
	Ergonomics of the form, sizes and the arrangement of GCS control panels	Correspondence between the form of control panels and the GCS service algorithm Correspondence between the sizes of control panels and the GCS service algorithm Correspondence between the mutual arrangement of control panels and the GCS service algorithm of GCS control panels and the operator`s anthropometric and psycho-physiological characteristics (taking into Correspondence between the look-out angles account the degree of importance and their application frequency)
	Ease of perception of the displayed information	The levels of direct and inverse contrasts The coefficient of uneven brightness of information units The unevenness of the screen field brightness Linear values of image distortion in the screen area
	Ergonomics of visual information display devices	Compliance of the outside lightning of signs, signals, and inscriptions with ergonomic requirements Compliance of information coding methods with ergonomic requirements Compliance of the sizes of signs, signals, and inscriptions with ergonomic requirements Compliance of a configuration of signs, signals, and inscriptions with ergonomic requirements Compliance of viewing angles of signs, signals, and inscriptions with the ergonomic requirements
	Ergonomics of acoustic information devices	Correspondence of message types to the GCS operation algorithm (a bell, buzzer, siren, musical tone or voice) Correspondence of the nature of messages to the GCS operation algorithm (simple, complex, periodic, and continuous with disconnection at response time)
	Ergonomics of tactile information devices	Conformity of the information provision means to the GCS operation algorithm (vibration, configuration, temperature, and amperage) Compliance of levels of electrical, chemical, and thermal signal levels with the ergonomic requirements
	Convenience of control effectors design	Conformity of the form and the constructive execution of control effectors to ergonomic requirements Conformity of the sizes of control effectors to the ergonomic requirements Correspondence between the effort required to bring the controls in action and ergonomic requirements
	Ergonomic placement of control effectors	Correspondence of the nature of the operator's control movements to the functional state of the controlled system Compliance of the combination methods of several control effectors with the ergonomic requirements Correspondence between distance to controls (taking into account the degree of importance and frequency of their application) with the operator`s anthropometric characteristics Availability and adequacy of the protection means for control effectors
	Rationality of GSC layout	Compliance of GCS sizes with ergonomic requirements Optimal placement of display devices and control effectors

Continuation of table 2

Group of indicators	Complex indicator of the 1st level	
	Complex indicator of the 2nd level	Individual indicator
	GCS assimilation	
	Information Model Quality	Adequacy of the information model Stereotypy of the information model Adequacy of information on the product and process Redundancy of information on the product and process Structural ordering of the information model
	Completeness and convenience of GCS operation manual	The level of operation manual completeness Clarity of the instructions Quality of material design
	GCS maintenance	
	–	Comfort and the rate of maintenance, repair, preparation for operation The complexity of the maintenance and repair algorithm Ease of access to adjustable and replaceable elements Availability of technical failure diagnostics means
	Ergonomics of operational documentation	Completeness of operational documentation Convenience of the material presentation structure, the levels of information decoding and re-coding Quality of illustrations, schemes, graphic elements, and documentation format Documentation storage capability
	Ergonomics of equipment and tools required for the GCS operation	Ease of use of instruments, controls and diagnostic equipment Compliance of lighting equipment with the specified norms of general light and spotlighting Convenience and safety of use of a tool while working in the given conditio (especially in the field environment)
	GCS hygiene	
	Physical factors	Indicators of the illumination level of work surfaces and controls
	Chemical factors	Presence of hazardous components in materials and coatings
	GCS safety	
	–	Safety level of the factors of a mechanical origin Safety level of the factors of a chemical origin Safety level of the influence of an electric current Safety level due to the completeness of taking into account the consumer`s psycho-physiological characteristics Safety level conditioned by the algorithm of the GCS operation
Aesthetic indicators	**GCS artistic expression**	
	Decorative expression of the GCS form	Correspondence between the GCS artistic image and its purpose Correspondence between the GCS artistic image and modern ideas about the products of a certain type
	GCS form originality	Originality of the used GCS formation principles: plastic, compositional, layout Peculiarity of applied decorative and colour-graphic elements Adequacy of GCS originality methods for the expediency requirements
	GCS form fashionableness	Correspondence of the colour-graphic solution, GCS finishing to "fashionable" decorating methods Correspondence of GCS compositional and plastic characteristics (or its packaging)to "fashionable" methods of form making
	Decorative expression of the GCS form	Decorative expression of the used materials and coverings Correspondence between the GCS decorative expression methods and the requirements of expediency
	Stylistic unity of the GCS form	Compatibility of GCS design features with each other within the limits of a chosen style (level of eclecticism) Compatibility of GCS design features with other components of a system within the limits of a chosen style
	Rationality of the GCS form	
	Functional and constructive conditionality of the GCS form	Adequacy of the GCS form for its the purpose and operating conditions (for example, manual and portable GCS) Adequacy of the GCS form for its composition and layout scheme Suitability of the use of constructive methods of organizing GCS form elements
	Technological conditionality of the GCS form	Compliance of the GCS form with the requirements of its manufacturing technology

Continuation of table 2

Group of indicators	Complex indicator of the 1st level	
	Complex indicator of the 2nd level	Individual indicator
	Integrity of the GCS compositional-plastic form solution	
	Harmony of the GCS three-dimensional structure	Interdependence of primary and secondary elements of the GCS form in size, proportions and scale The degree of GCS scale and its elements (visual matching to the size of the human body)
	GCS architectonic form	Manifestation in the form of the nature of GCS structural loads Visual balance of the GCS three-dimensional, compositional and plastic structure
	Plasticity of the GCS form	Integrity of three-dimensional and plastic solution of the GCS form Correspondence between the volumetric and plastic solution and applied materials, and manufacturing technology
	Artistic and graphic expression	Compositional validity of the arrangement of graphic elements on the GCS parts The degree of conformity of the nature of the fonts to the semantic value of the inscriptions Expression of GCS functional graphics
	Color-graphic compatibility of elements	Interdependence between colour and graphic elements Subjection of colour and graphic elements to the general GC compositional and colour-graphic solution
	Color and texture compatibility of elements	Compatibility of different types of materials, composition, textures, coatings used in the GCS with each other Consistency of different types of materials, composition, textures, coatings with the GCS shape, purpose, and operating conditions
	Perfection of production and the preservation of the gcs marketable condition	
	Fineness of contours	Fineness of contours, fillets, and joints of the elements of the GCS form
	Quality of the GCS surface treatment	Careful treatment of GCS surfaces Careful application of decorative and protective coatings
	Clarity of signs and accompanying documentation	Quality of GCS graphic elements, PDT and promotional materials
	Resistance to damage	Protection of the GCS form elements and surfaces against damage, attrition, and decorative covering quality changes
Functional indicators	**Perfection of the main GCS function performance**	
	Efficiency of GCS use	The degree of satisfaction with the control function in the UAV flight
	Versatility of GCS use	
	The range of GCS use for its intended purpose	The range of conditions and capabilities for the given GCS use for various UAVs
	Perfection of auxiliary operations	
	Perfection of preparatory operations	Suitability of the GCS to perform auxiliary transportation operations and preparation for operation
	Perfection of finishing	Suitability of the GCS to perform auxiliary operations of disassembly, cleaning, packaging and transportation
	Perfection of GCS auxiliary operations	Perfection of operations on watching videos (for example, search of the necessary record)
Operational indicators	**Ease of GCS operation**	
	–	Perfection of the GCS use during service operations accompanying implementation of the main and auxiliary functions
	Ease of GCS maintenance	
	–	Perfection of preparatory and final operations, and also GCS regulation in the course of operation GCS suitability to perform auxiliary operations of maintenance, storage, and disposal
	GCS reliability	
	GCS failure-free operation	Preservation of the basic parameters of GCS operation in time and within the limits corresponding to the set operating conditions
	GCS durability	Preservation of the basic parameters of GCS operation before the limit state is achieved at which their fulfillment becomes impossible. When calculating durability, it is determined the GCS service life or resource in conditions as close as possible to its specific operational process
	GCS maintainability	Possibility of GCS urgent repair in field conditions The average duration and complexity of the current GCS repair in stationary conditions

End of table 2

Group of indicators	Complex indicator of the 1st level	
	Complex indicator of the 2nd level	Individual indicator
Socio-cultural indicators	**GCS social address and consumer class**	
	–	Correspondence of the GCS to the structure of needs of a certain target audience
	Compliance with the optimal GCS nomenclature	
	–	Efficiency of GCS use in the operational or projected GCS system of a certain type
	GCS moral aging	
	–	The GCS service life is limited by the introduction of the new GCS types of higher quality
Design and marketing indicators	**The degree of GCS compliance with the world level**	
	–	The level of GCS design and ergonomic characteristics as compared to the products of the leading manufacturers of similar products
	Compliance with the requirements of the potential target market	
	–	The degree of market demand for a particular GCS
Design and environmental indicators	**The nature and extent of the GCS impact on the environment**	
	–	The impact of GCS on the environment during its life cycle
	Utilization degree of GCS materials	
	–	The output of recycled materials

Conclusions

The expansion of the UAV application causes a sharp complication of unmanned aerial vehicle systems and the need to adapt their design and functionality to operator`s psycho-physiological, intellectual, anthropometric, and other features necessitating the development of the new approaches and methods of UAVS design.

Nowadays, the need for in-depth pre-design UAVS ergodesign research based on experimentally and analytically developed requirements for UAVS components and their ergodesign quality indicators formulated on this basis is becoming more and more urgent.

Currently, based on the results of UAVS ergodesign studies, we can consider the need for the in-depth study of the peculiarities of operators` interaction with the UAVS functional elements in different operational situations. In order take into account the human factor in all UAVS functional structures when creating new UAVS types to the maximum extent and ensuring the greatest cost-effectiveness, it is extremely important to involve specialists in ergodesign at least at the stage of the formation of a technical task for the product.

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Abbreviations

UAVS – Unmanned aerial vehicle systems
ICAO – The International Civil Aviation Organization
UAV – Unmanned Air Vehicle
GCS – ground control stations
RP – remote pilots
AW – automated workstations

Nova Poshta address and the telephone number for delivery: Kyiv, 04208, V. Poryka Avenue, b.13, ap. 27; tel.: +380986067914 Kardash O.V.
The authors confirm compliance with all established requirements,

Кардаш Олег Васильович
доктор технічних наук з технічної естетики,
професор кафедри дизайну Інституту мистецтв
Київського університету імені Бориса Грінченка
02154, Україна, м.Київ, бул. І. Шамо, 18/2
kardash.o.v@ukr.net
Контактний тел.: +380986067914
Номер ORCID: https://orcid.org/0000-0002-8497-3453
Kardash Oleh Vasyl
doctor of engineering sciences from technical aesthetics
a professor is a design department Institute of arts
kyiv borys grinchenko university
02154, Ukraine, м.Київ, boulevard I. Shamo, 18/2
kardash.o.v@ukr.net
Pin tel.: 380986067914
Number of ORCID : https://orcid.org/0000 - 0002-8497-3453

Рубцов Анатолій Львович
Старший науковий співробітник Національного авіаційного університету
03058, Україна, м. Київ, пр. Любомира Гузара, 1, корпус 9
rubal@ukr.net
095-008-04-77
Rubtsov Anatolii Lvovych
Senior Researcher
The Research Part of the National Aviation University
03058, Ukraine, Kyiv, 1, Liubomyra Huzara ave., building 9
rubal@ukr.net
Pin tel.: 38095-008-04-77
Number of ORCID : https://orcid.org/0000-0002-7992-8236

Свірко Володимир Олександрович
канд. психолог. наук, – директор Українського науково-дослідного інституту дизайну та ергономіки Національного авіаційного університету
03058, Україна, м. Київ, пр. Любомира Гузара, 1, корпус 9
ndi-design@ukr.net
066-574-79-05

Svirko Volodymyr Olexandrovych
cand. of psychol. sciences
Director the Ukrainian Research Institute of Design and Ergonomics of the National Aviation University
03058, Ukraine, Kyiv, 1, Liubomyra Huzara ave., building 9
ndi-design@ukr.net
Pin tel.: 38066-574-79-05
Number of ORCID : https://orcid.org/0000-0002-6482-6827