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Тема: «Особливості розробки програми випробувань БЛА та його обладнання»

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MASTER DEGREE THESIS
ON SPECIALITY
”AVIATION AND ROCKET-SPACE ENGINEERING”

Topic: «Features of test program development for the UAV and its equipment»

Fulfilled by: ______________ **Vladyslav CHERNOV**

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2. Термін виконання роботи: з 11 жовтня 2021 р. по 31 грудня 2021 р.

3. Вихідні дані до роботи: нормативні документи та технічні стандарти (STANAG 4671, CS-23, CS-VLA), тлог типового польоту безпілотного літального апарату з нерухомим крилом, основні характеристики безпілотного літального апарату: маса – 250 кг, розмах крил – 5 м.

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6. Календарний план-графік

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1	Аналіз літературних джерел щодо класифікації безпілотних літальних апаратів.	11.10.2021–14.10.2021	
2	Аналіз документації щодо вимог до безпілотніх літальних апаратів.	15.10.2021–21.10.2021	
3	Аналіз втомної теорії та втомних випробувань.	21.10.2021–27.10.2021	
4	Дослідження тлогу типового польоту та програмного забезпечення для взаємодії із даними.	28.10.2021–31.10.2021	
5	Розробка алгоритму визначення спектру навантаження.	1.11.2021–14.11.2021	
6	Виконання частин, присвячених охороні праці та охорони навколишнього середовища.	15.11.2021–30.11.2021	
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TASK

for the master degree thesis

Vladyslav Chernov

1. Topic: «Features of test program development for the UAV and its equipment», approved by the Rector’s order № 2173/ст from 8 October 2021 year.

2. Period of work: from 11 October 2021 year to 31 December 2021 year.

3. Initial data: normative documents and technical standards (STANAG 4671, CS-23, CS-VLA), the tlog of an typical flight of an, the main characteristics of an unmanned aerial vehicle: weight - 250 kg, wingspan - 5 m.

4. Content: classification of unmanned aerial vehicles, comparative analysis of existing documents and their application to the certification of unmanned aerial vehicles, creation of an algorithm for determining the load spectrum for the validation of fatigue characteristics.

5. Required material: power point presentation, drawings, tables and diagrams.

6. Thesis schedule:

№	Task	Time limits	Done
1	Research literature on classification of unmanned aerial vehicles.	11.10.2021–14.10.2021	
2	Analysis of documentation on requirements for unmanned aerial vehicles.	15.10.2021–21.10.2021	
3	Analysis of fatigue theory and fatigue tests.	22.10.2021–27.10.2021	
4	Study the tlog of a typical flight and software for interacting with data.	27.10.2021–31.10.2021	
5	Development of an algorithm for determining the load spectrum.	1.11.2021–14.11.2021	
6	Implementation of the parts, devoted to labor and environmental protection.	15.11.2021–30.11.2021	
7	Edit and correct the draft, modify the format.	1.12.2021–31.12.2021	

7. Special chapter advisers:

Chapter	Adviser	Date, signature	
		Task issued	Task received
Labor protection	PhD, associate professor Victoria KOVALENKO		
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8. Date of issue of the task: 8 October 2021 year.

Supervisor: ___________ Sviatoslav YUTSKEVYCH

Student: ___________ Vladyslav CHERNOV

РЕФЕРАТ

Пояснювальна записка дипломної роботи магістра «Особливості розробки програми випробувань БЛА та його обладнання»:

54 с., 19 рис., 2 табл., 23 джерела

Ця магістерська робота присвячена дослідженню класифікації безпілотніх літальних апаратів, аналізу існуючих документів сертифікації, створення алгоритму визначення спектру навантаження для валідації втомних характеристик.

Методологія розробки базується на нормативних документах та технічних документаціях, програмному забезпеченні для безпілотних літальних апаратів, теорії втомного навантаження.

Практичною цінністю роботи є запропонований алгоритм визначення спектру навантаження на базі журналу даних, отриманого у польоті.

Матеріали диплома магістра можуть бути використані в авіаційній промисловості та в навчальному процесі, при проектуванні безпілотних літальних апаратів.

Безпілотний літальний апарат, дрон, тлог, сертифікація, класифікація, алгоритм, спектр навантаження.

ABSTRACT

Master degree thesis "Features of test program development for the UAV and its equipment":

54 pages, 19 figures, 2 table, 23 references

This master thesis is dedicated to the study of the classification of unmanned aerial vehicles, analysis of existing certification documents, the creation of an algorithm for determining the load spectrum for the validation of fatigue characteristics.

The design methodology is based on regulatory documents and technical documentation, software for unmanned aerial vehicles, the theory of fatigue load..

Practical value of the work is the proposed algorithm for determining the load spectrum on the score of the data log obtained in flight.

The materials of the master's diploma can be used in aviation industry and in the educational process, in the design of unmanned aerial vehicles.

Unmanned aerial vehicle, drone, tlog, certification, classification, algorithm, load spectrum.

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ABBREVIATIONS

UAV - Unmanned Aerial Vehicle
EASA – European Union Aviation Safety Agency
MTOM – Maximum Take-Off Mass
DFF - Damaging Force Factor
GAG – Ground-Air-Ground
CS – Certification Specification
PDRA - Predefined Risk Assessment
ILS - Incremental Load Spectrum
RLS - Representative Load Spectrum
UAS - Unmanned Aerial Vehicle System
ICAO – International Civil Aviation Organization

INTRODUCTION

With the outbreak of World War I in 1914, humanity entered an era of postmodernism. Most, if not all, values have been rethought. Numerous industries have also been rethought. Characteristic features of this cultural paradigm are blurred borders and globalization. The latter is well facilitated by the rapid and dynamic development of science and technology that has been observed in recent decades. Many countries cooperate in many areas. As a result, new, previously unavailable types of goods and services have emerged. They have stimulated the development of the industry and encourage manufacturers to experiment, improve designs and improve the customer experience.

Aviation has been and remains a springboard for the introduction of new advances in science. This is especially true for the military, where budgets and human resources are less limited. In turn, the civil aviation industry in recent decades has taken a niche as the safest and fastest mode of transportation of people and goods. Many statistical and meta-analyzes confirm this.

The rapid development of unmanned aerial vehicles (UAVs) has been observed since the 1990s, when the usefulness of these aircraft was confirmed during hostilities. This development is the result of rapid technological progress (including information technology). Various functional implementations, their combinations allowed to create an interesting and modern UAV, which successfully combines quality and functionality in a single concept.

In recent years, lots UAVs for civilian use have been developed. There is a departure from the conservative drone perception. Users can be found in various fields, eg. among land management companies, meteorological institutions, universities, government agencies, etc. Potential applications include border monitoring, disaster surveillance, forest, plant and animal monitoring, road and rail, and more. Researching what new functions a classic UAV can be filled with in the short term and what practical implementations of added value will contribute to its transformation is an important challenge today.

The design and commissioning of new aircraft must be preceded by in-service safety studies. Today, the number of UAVs is growing rapidly, in proportion to the growing demand for their operation. There are standards and requirements for their manufacture and use, but they are mostly military (NATO STANAG 4671). If the trend is for civilian purposes, peaceful operation should be explored in more depth and comprehensively. This is a basic problem that is directly related to the availability, globalization and facilitation of ways to obtain the information we are interested in.

Accordingly, the issue of certification tests of civilian UAVs is relevant.

The reason for the introduction of the new aircraft is to determine its safe service life. Currently, in practice, there are two ways to determine the service life of the aircraft. The first method is based on the experience gained during the use of similar types of UAVs. Because this is only an estimate, this method is less reliable. It does not guarantee 100% repeatability, as it is not a fact that the operating conditions will be the same.

The second method is based on fatigue tests, during which the expected loads are applied to the aircraft. To assess fatigue life by calculation or experiment, it is necessary to know the spectra of the load on the glider, to investigate the specifics of each such aspect. Again, these are only approximate calculations and predictions of how the device will behave.

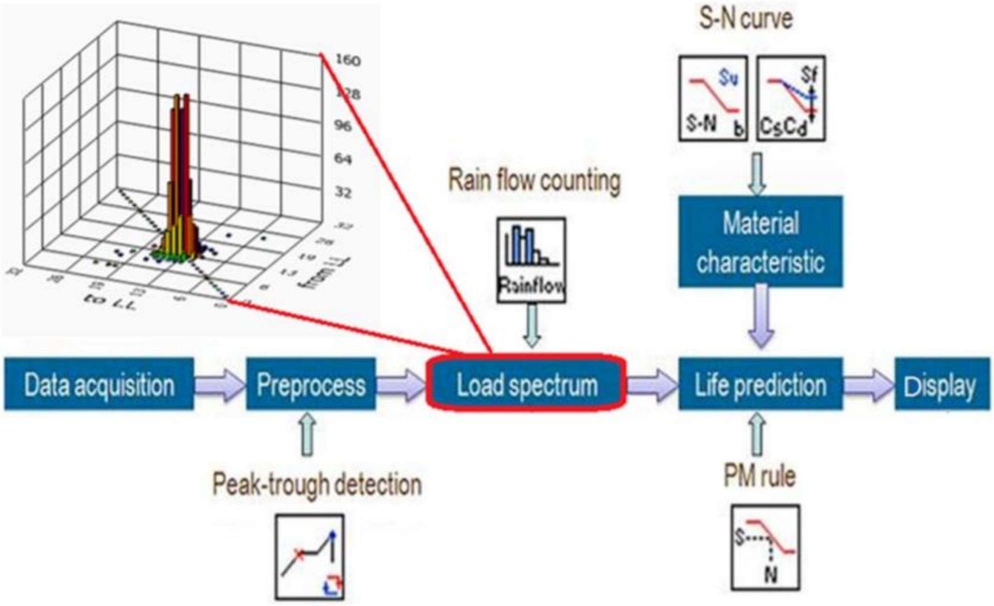

Fig. 1 Calculating scheme of fatigue life

PART 1. DRONES CLASSIFICATION

1. 1 Genaral definitions

Technological progress has significantly affected the big variety of spheres, from cases to doing business to international conflicts. These modifications can be clearly imagined by taking benefits of these technological advances.

Unmanned aerial vehicles (UAVs), also known as distant-controlled aircraft, are perfect example of visualizing alternate. Unmanned aerial vehicles do not require any piloting and can be operated solo or distantly. UAVs are an essential part of the unmanned aerial vehicle system (UAS), which includes unmanned aerial vehicles, communications equipment and ground control station. The UAV overcomes the restrictions of the ground system in terms of appliance, agility and constancy. The unmanned aerial vehicle was created for protection, surveillance and combat purposes. Perhaps in 1916 the first semi-automatic aircraft (air torpedo) was advanced. In 1933, the Royal Navy serviced drones to fire. Later, with the advent and assimilation of modern navigation sensors, unmanned aerial vehicles became an indispensable part of the armed staff. The advent of technology has not only eliminated restrictions on the use of unmanned aerial vehicles in the armed forces, but also spread out their wings for commercial purposes related to land management, science, recreation, delivery of goods, photogrammetry and many others.

Unmanned aircraft system operator (UAS operator) means any legal or natural person operating or intending to operate one or more UAS [1].

Remote pilot means a natural person responsible for safely conducting the flight of a UA by operating its flight controls, either manually or, when the UA flies automatically, by monitoring its course and remaining able to intervene and change its course at any time[2].

Uninvolved Persons means persons who are not participating in the UAS operation or who are not aware of the instructions and safety precautions given by the UAS operator.

Assemblies of People means gatherings where persons are unable to move away due to the density of the people present [2].

1.2. Classification of unmanned aerial vehicles

Due to the fact that many aircraft fall under the definition of a drone, there is currently no strict and clear systematics. Commonly accepted categories of classification in the variety of UAVs: aerodynamic features, landing and takeoff veriety, mass and mission range.

1.2.1. Based on aerodynamics

Various unmanned aerial vehicle systems have been developed, some of which include fixed propeller UAVs, choppers, multi-propeller UAVs, motor parachute and gliders, vertical takeoff and landing drones, commercial unmanned aerial vehicles, and others. They are all designed for a specific mission and have their pros and cons. Fixed-wing drones are very simple and easy to design and manufacture, thanks to the successful combination of knowledge of large aircraft with minor modifications and improvements. Fixed wings are the main elements that generate lift in response to forward acceleration. The speed and steep angle of the air flow on the fixed wings control the rise. To launch the flight, fixed-wing unmanned aerial vehicles require a higher initial speed, and the thrust-to-load ratio is less than one. Comparing a fixed-wing and a multi-propelled UAV with the same payload, the first drones are more comfortable with lower power requirements and thrust load. Rudder, ailerons and elevators are used for yaw, roll and pitch angles to control the orientation of aircraft [3].

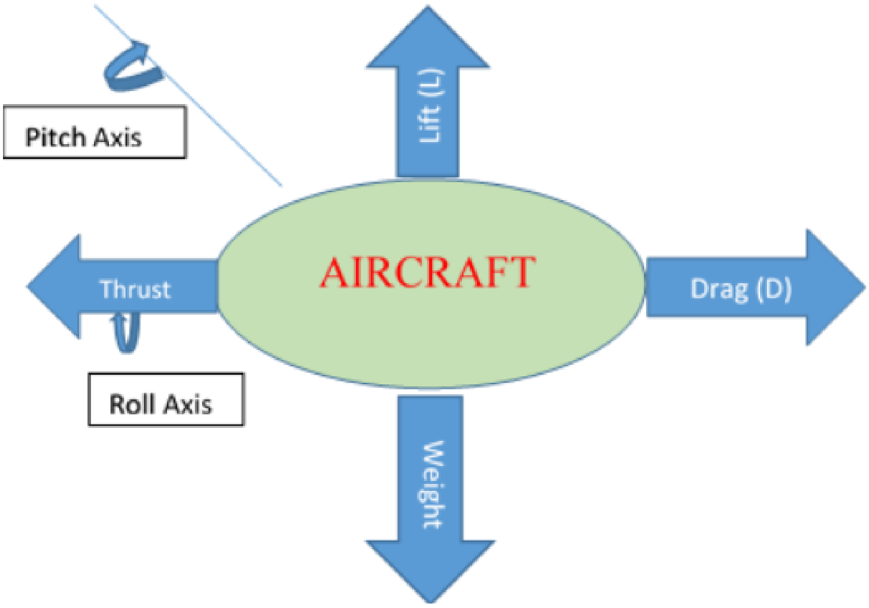

Fig. 1.1 Fixed Wing UAV Aerodynamics

Drones with movable (flapper) wings were designed like insects and birds such as small hummingbirds or large dragonflies. Light and flexible wings are inspired by the feathers of insects and birds, which demonstrate the usefulness of the weight and flexibility of the wings in aerodynamics. However, these wings are complex due to their heavy aerodynamic performance. This type can maintain stable flights in windy conditions, unlike fixed-wing drones. Lightweight and flexible wings that provide a flapper motion with an actuation mechanism have been studied by aerodynamic scientists and biologists who know the structure of such wings [3].

Multicopter: The blade of the main rotor produces thrust, which is used for both lifting and moving. Multi-rotor unmanned aerial vehicles are capable of vertical takeoff and landing and can "hover" in the air, unlike aircraft. The multicopter is designed for the number and location of motors and propellers on the frame. Their ability to oscillate, their ability to maintain speed makes them ideal for observation and monitoring. The only problem with multicopters is that they require more power consumption and limit their endurance.

1.2.2. Based on the type of landing and takeoff

Horizontal takeoff and landing and vertical takeoff and landing. The first option can be considered in a UAV with a fixed wing. They have a high takeoff speed and smooth landing. Vertical take-off unmanned aerial vehicles are the most convenient in terms of flight control, landing and hovering, but their speed is limited due to the slowing down of retreating propellers.

1.3. NATO STANAG

The most common type of classification of unmanned aerial vehicles is the classification by weight and range. Because it based on well-known normative document NATO STANAG 4671 [4]. The range includes the distance at which the ability to control and fly the UAV remains.

Table 1. NATO STANAG classification

Class	Category	Operational altitude	Maximum Weight	Mission Radius	Type
Class I	Micro	Up to 70 m AGL	<66 J	5 km (LOS)	Fixed wing, multirotor
	Mini	Up to 900 m AGL	>15 kg	25 km (LOS)	Fixed wing, multirotor
	Small	Up to 1500 m AGL	>150 kg	50 km(LOS)	Fixed wing, multirotor
Class II	Tactical	Up to 5600 m AGL	150-600 kg	200 Km (LOS)	Fixed wing
Class III	MALE	Up to 14500 m MSL	>600 Kg	Unlimited (BLOS)	Fixed wing
	HALE	Up tp 20000 m	>600 Kg	Unlimited (BLOS)	Fixed wing
	Strike/Combat	Up tp 20000 m	>600 kg	Unlimited (BLOS)	Fixed wing

Each of these categories is classified by purpose: from UAVs used in reconnaissance or military, to those designed for transportation cargo to hard-to-reach places and look like real planes.

1.4 EASA

EU regulations [1,2] set the framework for the safe operation of civilian drones in the European skies. They use a risk-based approach and thus do not differentiate between the leisure or commercial activities of drones. They take into account the weight and characteristics of the civilian drone and the operation it is to perform.

According to EASA [5], civilian UAVs are divided into three groups:

- Open category. It aims to reduce the risk in the operation of civilian drones, where safety is ensured provided that the operator of the civilian drone meets the relevant requirements for its intended operation. Operational risks in the "open" category are considered low, so no operating permit is required before the flight.

- Specific category. It covers riskier operations with civilian drones, where safety is ensured by the drone operator by obtaining a permit to operate from the national competent authority before the start of the operation. To obtain an operating permit, the drone operator must conduct a risk assessment that will determine the requirements necessary for the safe operation of the civilian drones [6].
- Certified category. Here the security risk is much higher. Therefore, certification of the drone operator and his device, as well as the licensing of the remote pilots are always required to ensure safety [6].

Conclusion to part 1

Most UAS designs have a limited Maximum Take of Mass (MTOM) up to a few hundreds of kilogram. Especially considering the expansion of urban operations, the vast majority of upcoming UAS operations is expected with UAS of limited mass. The operation of such UAS may often fall in the specific category, where operational approval is provided by the Competent Authorities, but the design of the UAS shall be certified by EASA for high risk operations or may be certified for lower risk ones (refer to EASA AMC and GM for comprehension of the overall policy) [1,2].

Once more experience has been gained with the certification of UAS with the application of the SC light UAS, EASA intends to transpose this SC into a CS.

For UA of higher maximum take-off mass more than 750 kg, closer to traditional aircraft or capable of carrying persons the certification basis may be established on the basis of existing manned aircraft CS (CS-23/27, CS-25/29), complemented with appropriate airworthiness standards from a CS-UAS, yet to be created, focused only on UAS-peculiar elements.

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PART 2. DEVELOPMENT OF FATIGUE LOADING SPECTRA

2.1 Theoretical derivation of fatigue damage

Fatigue is the process of gradual accumulation of damage in a structure (element, material) under the action of alternating stresses, leading to changes in physical and mechanical properties, initiation and propagation of cracks. A conditional measure of fatigue is the fatigue damage capacity which, as a rule, is determined by calculation (for example, using linear fatigue damage summation hypothesis, which is called Palmgren-Miner rule [7].

The ability of a structure (element, material) to resist fatigue is called fatigue strength.

Fatigue is subjected mainly to those elements of an aircraft structure which are loaded with tension during operation.

For modern UAV's, the weight of such structural elements ranges from 25 to 45% of the airframe weight.

Studies show that in the process of repeated loading of the structural elements there is some change in the natural vibration frequencies, electrical conductivity, physical and magnetic and some other properties of the material. However, all these changes occur quite intensively only at the beginning and end of the fatigue failure process and the prediction of the hazard based on the measurement results of the relevant characteristics has a low reliability. Therefore, currently the most reliable source of information about the fatigue fracture process is the crack that accompanies that fracture.

In service, about 90% of fractures start from the surface layer. Special experimental studies have established that the fatigue resistance of the surface layer of a part and structure is about 50% of the fatigue resistance of the underlying layers. This is due to an unfavorable difference in the energy bonding state of the material particles on the surface below it. On the surface of the material the metal particles have energetically unrealized bonds, which cause, for example, adhesion of the material, formation of oxide films in aluminum and titanium alloys, etc. Free energy bonds of surface layer particles eventually weaken the metal. The surface layer is present in all metals regardless of the type of crystal lattice and the presence of an oxide film, its thickness is 0.05 ... 0.50 mm.

Thus, fatigue resistance of details is mainly determined by the state of their surface layer and its damages and to a lesser extent by the state of the core (inner layers) of the material of details. Therefore, the special treatment of the surface layer of the parts in the process of manufacturing - is an important direction of increasing the durability of UAVs structures.

Thus, safety consideration is a fundamental requirement. Structural safety in terms of strength means both the property of the structure itself and the way to maintain its strength during long-term operation.

The assessment of the safety of a structure in terms of strength must show that within the established resource (service life) in the expected operating conditions (environment, typical range of loads, etc.) accidents and catastrophic situations due to design fatigue, corrosion damage and accidental factors are virtually improbable. Structural safety in terms of strength is ensured by:

- the appropriate design of the UAV;
- manufacturing processes of the UAV;
- maintenance and repair

Compliance with established rules and operating conditions and is confirmed by:

- the results of appropriate calculations;
- study of actual operating conditions, including environmental characteristics and operating loads;
- the results of flight performance tests;
- the results of laboratory and bench tests of full-scale structures, their parts, structural elements and materials;
- operating experience of UAV of the given type and (or) UAVs of similar types.

2.2. Software and parameters

The standard practice of empirical research is typical flight. The use of appropriate software is important for data planning, manipulation and analysis. The database is usually presented in the form of a log or tlog. Log parameters can be extracted in Text-, Matlab-, KML-file and others.

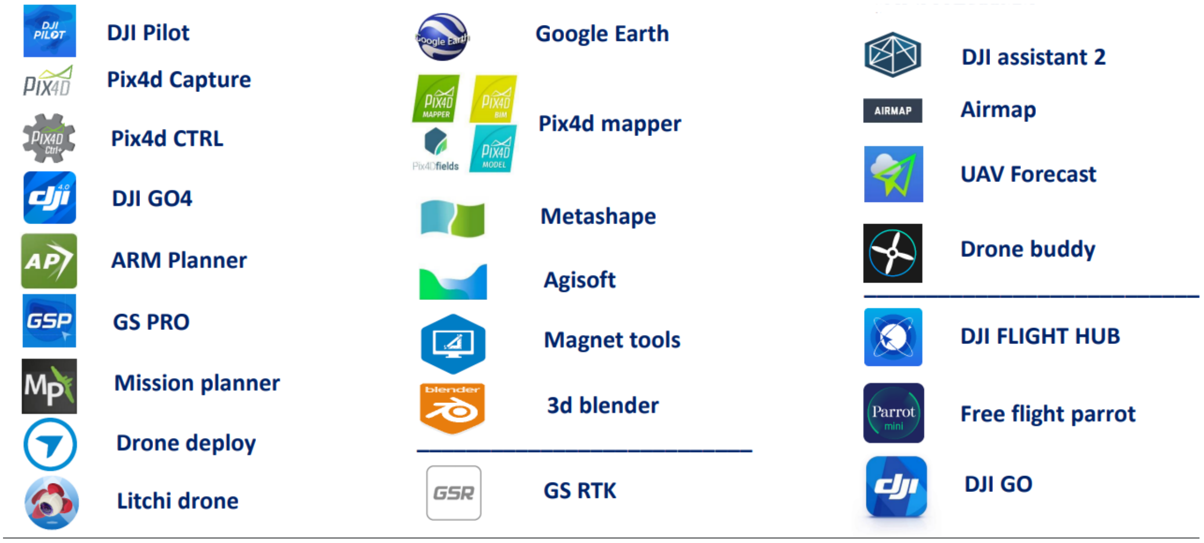


Fig. 2.1 The most common software used drone-software

One of the basic issues of fatigue testing is the spectrum of operational loads. It describes the statistics of changes in the load factor. Attention should be paid to the range of loads caused by both methods of UAV control. Knowledge of the load spectrum is necessary to determine the requirements for fatigue life of the UAV, which will be included in the airworthiness regulations of the UAV.

The analysis could be focused on the acceleration signal a_z, as it can be easily converted into a load factor n_z, taking into account the Earth's gravity and some correlation coefficients. This factor permissible values for the majority of fixed-wing drones are within (-4; + 4).

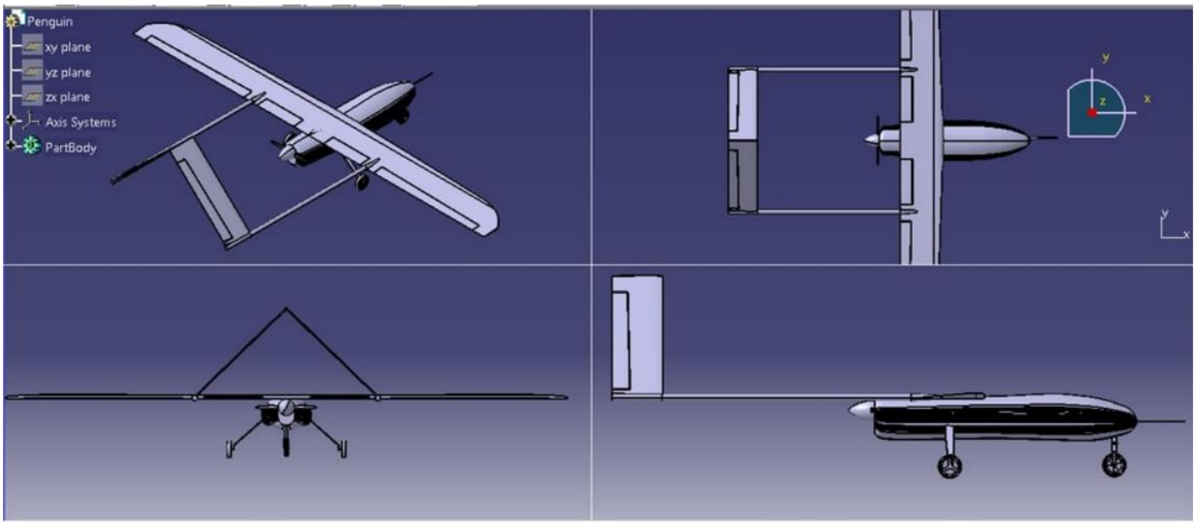


Fig. 2.2 Typical fixed-wing drone

The digital recorder plays a special role in the equipment of UAVs, and recently the main problem was the limited memory capacity, which forced people to look for sophisticated methods of recording the load spectrum. GPS usage allows to associate registered loads with flight path parameters, including terrain type. Figure 3 shows the flight path of a drone flying with a recorder on a vector map from Google Earth software of the area in 2018. In addition to the basic function of aircraft control, autopilot has another useful function of obtaining flight data. These data are great importance for the analysis of flight dynamics, including the determination of the load spectrum.

Fig. 2.3. Flight path

2.3. Determination of UAV load spectrum

A load signal should be first transformed to the form of a local extremes series, to be possible to calculate messages transfers. Usually the data-tlog signal range is divided into 128 levels, but for the goals of the convenient study, the signal levels number should be diminished to 64 or 32 per range.

In a case of this reduction usage it is possible to apply the software tools used in investigations of composite UAV’s, gliders and light aircraft load spectra. When raw signal in the form of local extremes can be used, algorithm [8] also allows to keen an eye on the loads variation speed. As a result, three different vectors of "local extremes", "time", and "velocity" could be obtained.

Next figure is the screenshot of the MissionPlanner software for viewing the tlog data. It shows some selected signals: air speed (green), altitude (red) and acceleration in the z-axis direction, perpendicular to the wing plane (blue).

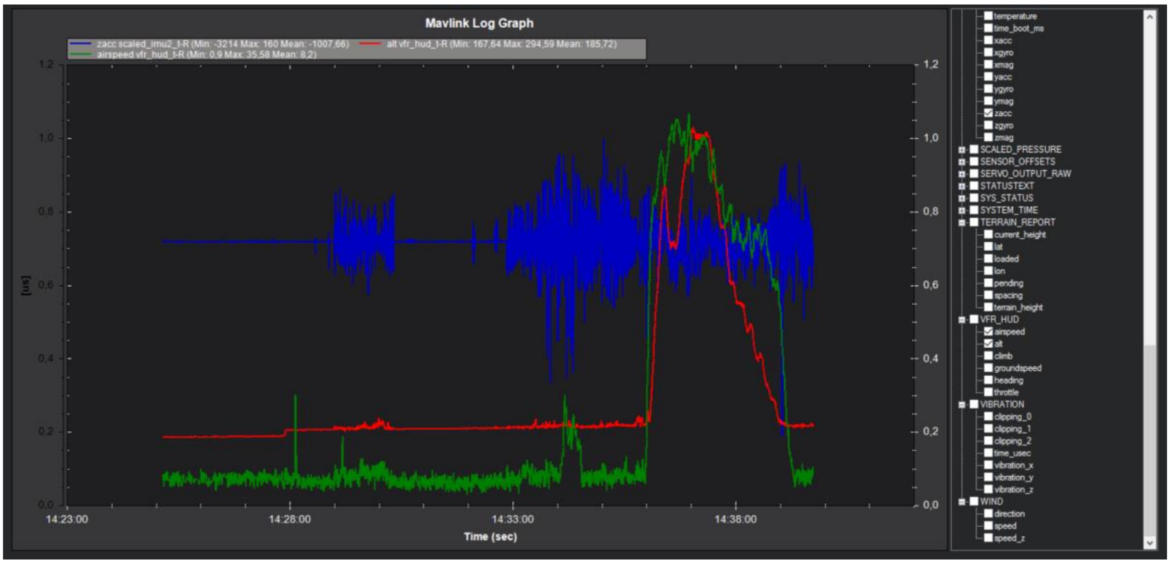


Fig. 2.3 Mavlink Log Graph – screenshot of Mission Planner software.

Graph shows the dependence of the parameters only schematically, not on a scale.

Transfer and Half-Cycles blocks can be applyied, as a method for load signal analysis, considering signals quantity transfered from each separated level to another.

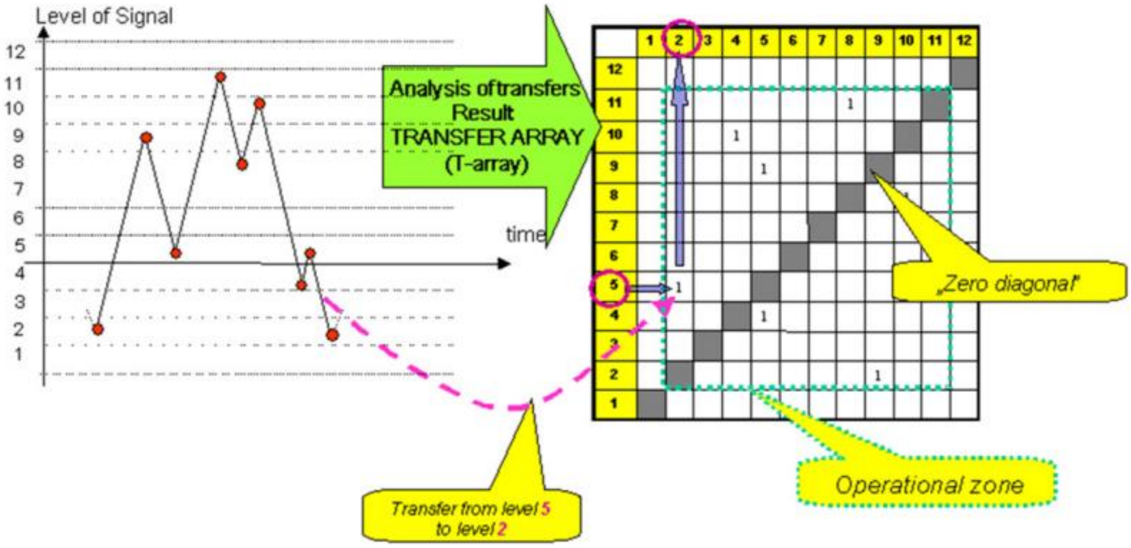


Fig. 2.4. T-array determination

Spectrum of recieved loads can be introduced as a half-cycle array (HC-array). Conducting of this block is closely related to the "Rainflow counting method” application. It was presented by japanese scientists Matsuishi and Endo in 1969 as one of the most efficient finding algorithms used for entire load cycles (i.e. load gains resulting from several load changes). The definition “half-cycle array” comes from the theoretical rule that each single load cycle consists of two half-cycles that are displayed simultaneously over and under the diagonal-line of the HC-array [9, 10].

Rainflow Counting Method principle is based on the similarity between the “flowing down raindrops” and the load halfcycles. Local extremes vector is oriented perpendicular to the time vector, positioned vertically downwards. Such location can be imagined as a multilevel roof of the japanese traditional building "pagoda" during rainfall. If count all “drops pathes” on load local extremes graph from both sides and to put them into corresponding cells of the array, the half-cycle block can be obtained. This operation is described in [11].

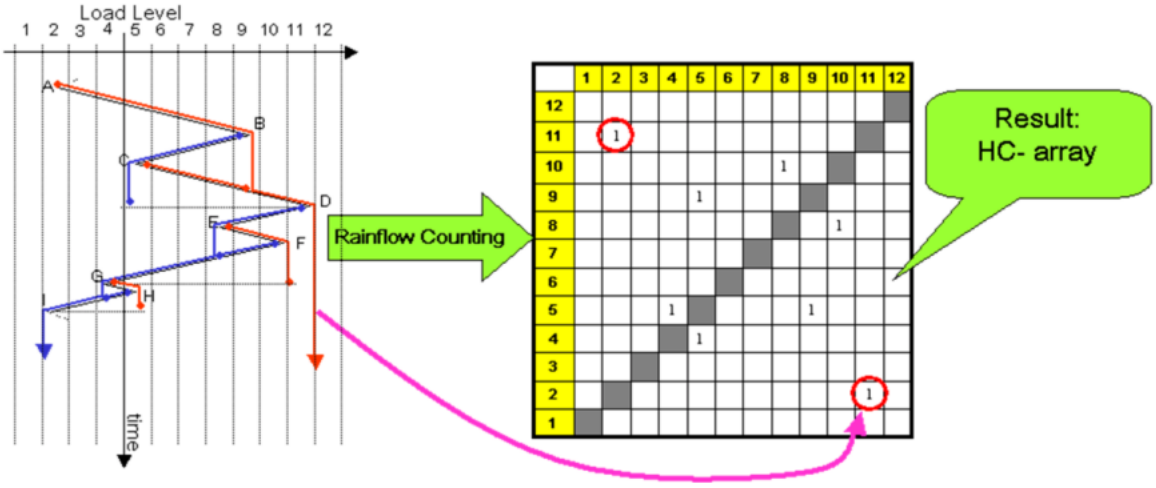


Fig. 2.5. Rainflow count method HC-array determination

For load diapason comparison especially appropriate the usage of so-called incremental load spectrum (ILS), because it represents visually the quatity of appearances for each load stage. Cells below and above the stripe made along the block main diagonal build the ILS from those values enumeration. Load value increasing by at least one level is equal to the sum of all the values of the cells. Load value increasing by at least two levels is equal to the sum of all table cells without first cells adjacent to the diagonal. Moving further away from the basic diagonal of the block is needed for counting appearances number for the next load stages. ILS has is of limited value for fatigue calculations, but still can be used for comparative analysis of different load spectra.

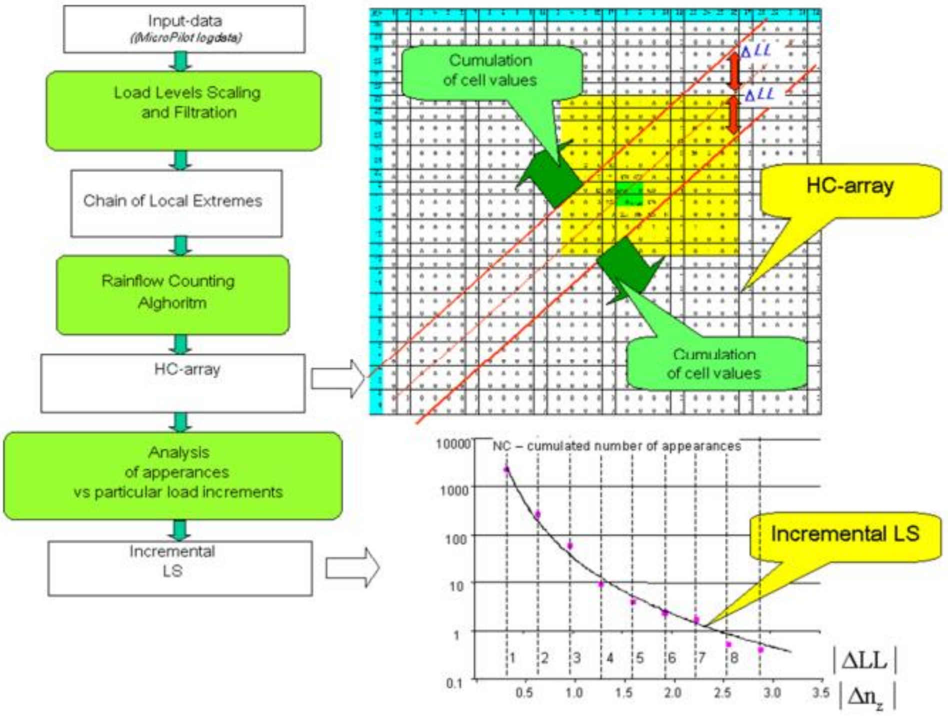


Fig. 2.6. Derivation of Incremental Load Spectrum

The UAV is controlled partly in a manual and partly in an automatic mode during missions. Thus, the advantagable feature of a T-array and HC-arrays is a so called operational zone, i.e. a square-shaped area of all cells containing of non zero values. The UAV is controlled partly in a manual and partly in an automatic mode during mission. T- and HC-block operational area deducted from the same signal have identical dimensions, but only the last can be used in fatigue damage analysis since a based T-array does not record the resulting signal levels changes after several transfers. As an example there are shown incremental load spectra withdrawn from the Transfer and the Half Cycle blocks obtained from the data-tlog.

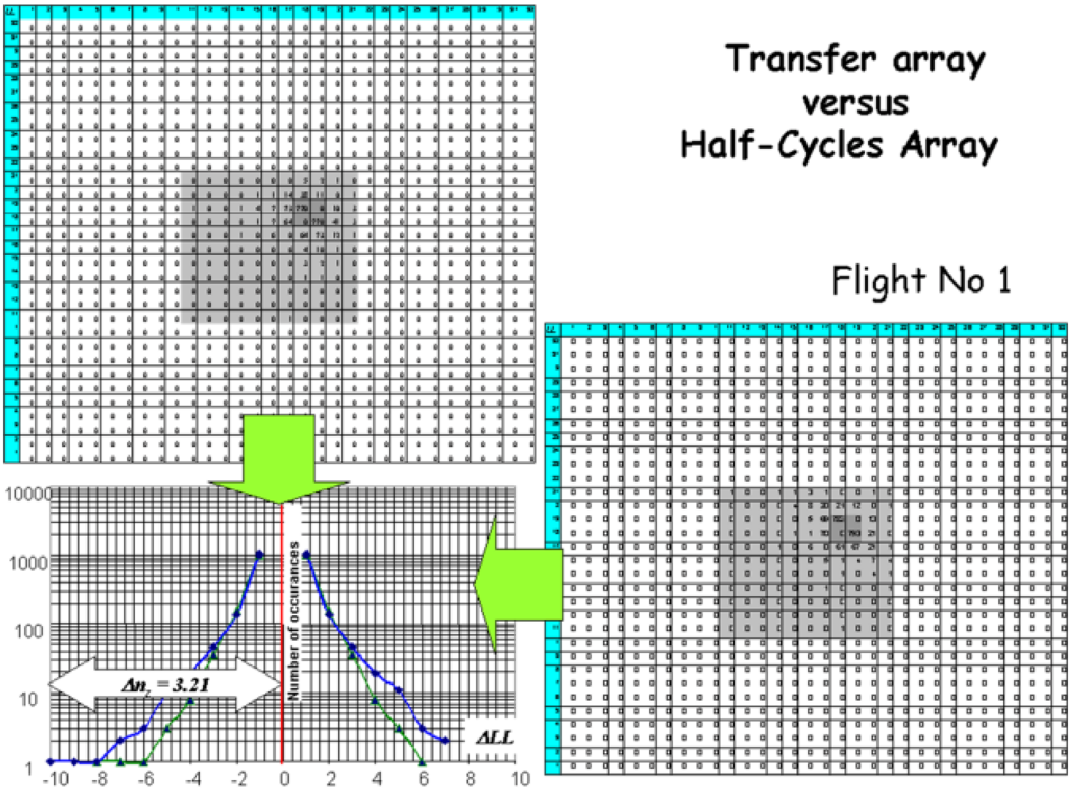


Fig. 2.7 T-array versus HC-array derived from the same signal

The Load increment maximum value is much lower in the case of usage the T-array algorithm that proves the cause why the Rainflow Method is so valid in fatigue calculations.

2.3.1 Load spectra for UAV in different ways of control and weather conditions

The methods considered in the previous section are used to calculate the loads of UAVs in different environmental conditions and operating regimes. The load parameters in the manual and automatic control mode are shown on figures

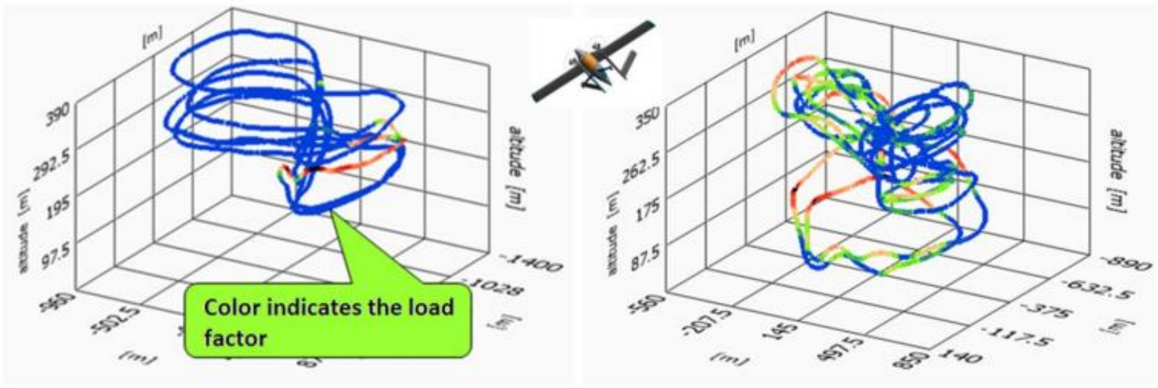


Fig. 2.8 Differences in the Load Spectra: Auto control mode (left), Manual control mode (right)

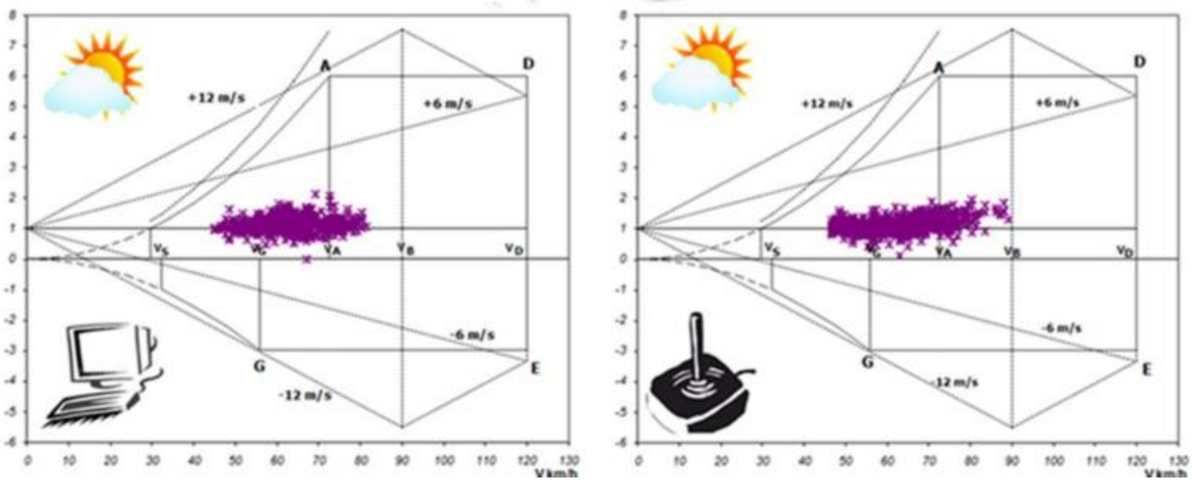


Fig. 2.9. Loads of a fixed-wing UAV in different control conditions

Loads reasoned by air disturbances can not be influenced in the manual control mode. Air turbulence can cause changes in flow and temporary changes in the angles of attack resulting in conversions in force during mission. The nature of the load is shown in Figure 2.10.

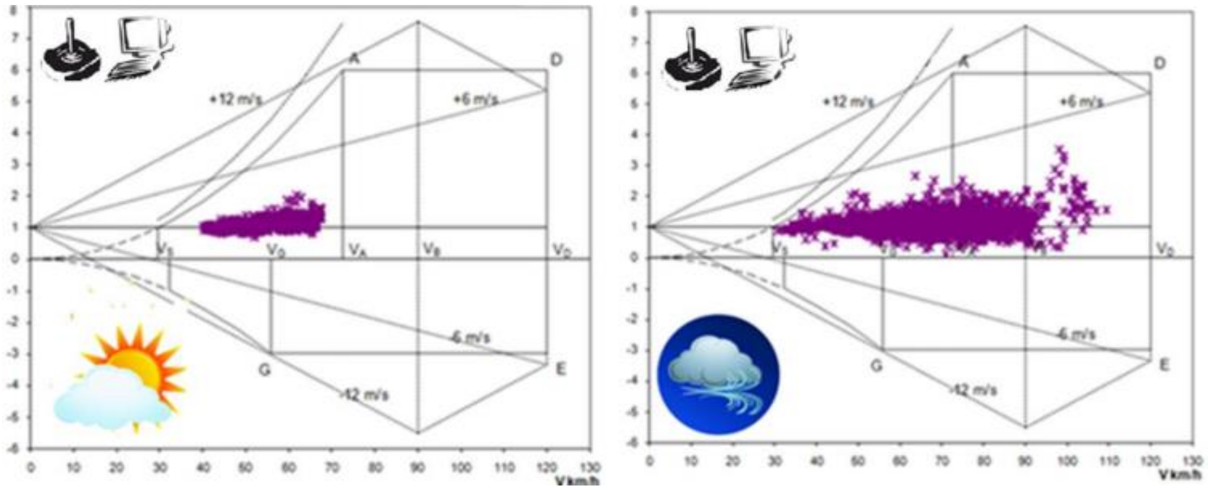


Fig. 2.10. Loads of the UAV in different weather conditions

Throughout the most flight time, a drone is controlled by an autopilot. However, situations when a remote pilot on the ground interferes to operate the aircraft manually still may occur. After examination a typical flight aerodrome-circle maneuver, the incremental difference spectra should be prepared. When the UAV is menages by an autopilot, the quantity of small amplitude load-increments is greater than when it is controlled manually. During manual manipulation, fewer low amplitude load-increments take place, while load-gains of higher variations occur (Fig.2.11)

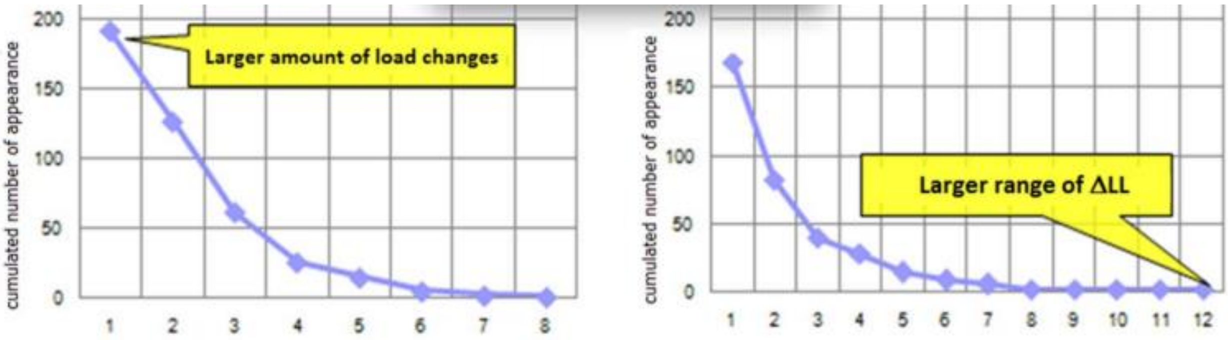


Fig. 2.11 Load spectrum dependent on automatic and manual mode

There is a possibility to retrieve the additional of the typical load spectra (RLS) for every kind of flight mission (as well for flight mission stage). They are represented as a mean value for the number of appereances that can be offset vertically by three standard deviations. Similarly, the highest value of the load gaining can be offset horizontally. Figure 2.12 shows the RLS for the aerodrome-circles flown by the fixed-wing UAV and the fatigue lifetime of aerodrome-circles RLS that are calculated using the Palmgren-Miner theory.

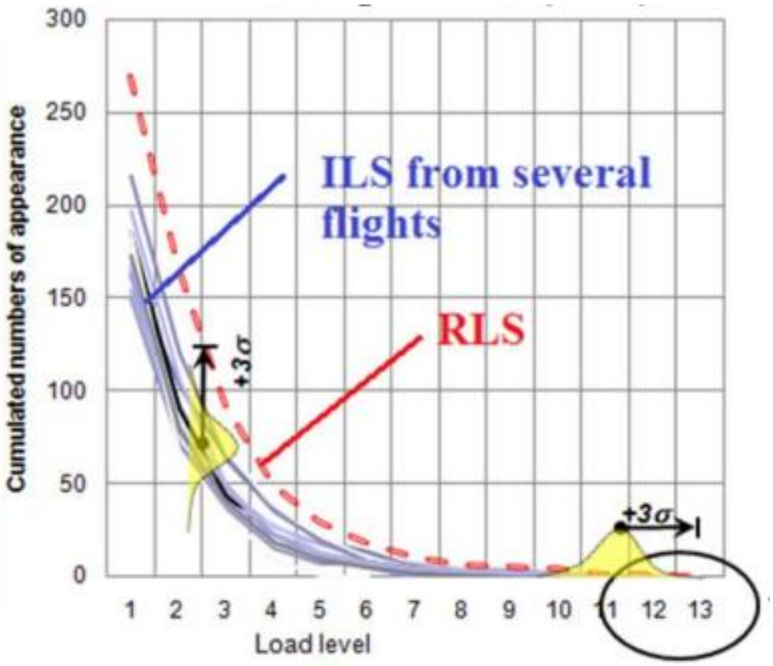
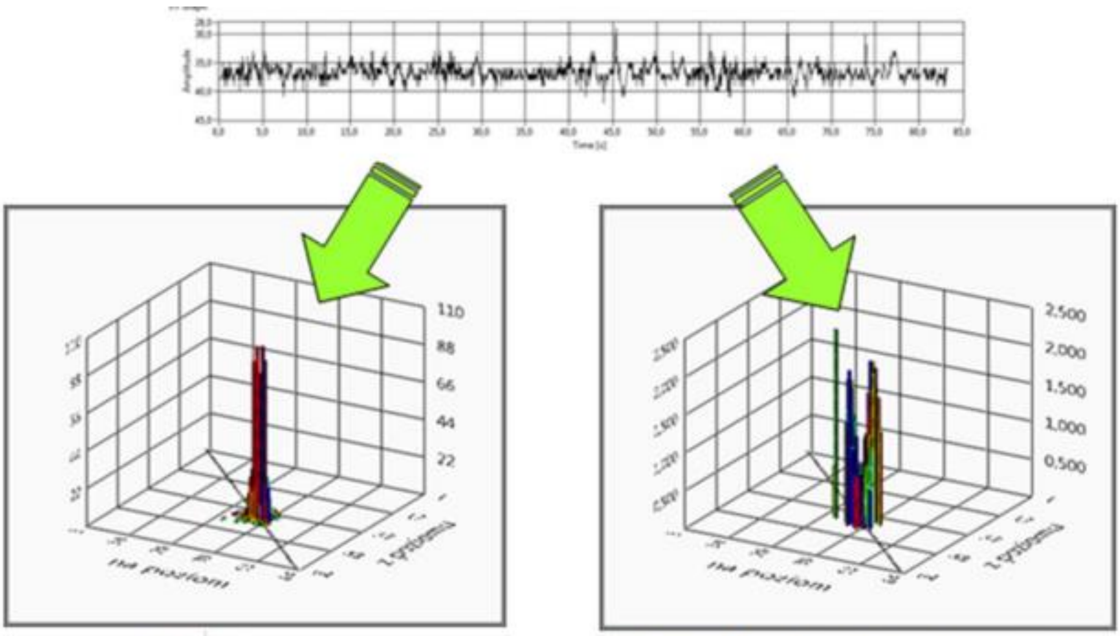


Fig. 2.12 Representative load spectrum for analyzed flights

2.3.2 Rate of load variation.

Typical algorithms to get the derivatives of load range are based only on the load local extremes data-vector, which does not consider the time flow. It means that each following shifting of load occurs in the same timestamp as the preceding one. It causes a lot of approximates but not accurate calculations. It is potentional to create blocks of the of load variety mean rates, considering the current loads change rate.

The method used to create such kinds of array is shown in Fig. 2.13.



HC-array **Rate of load variations - array**

Fig. 2.13 Representative load spectrum for analyzed flights

2.4 GAG cycle and lifetime determination

One the main problem in the process of determining the load spectrum for the fatigue test is the extrapolation of the measured spectrum. The problem here is that the measurement session lasts much less than the target life of the UAV, and based on the measurement covering several tens of flight hours. It is necessary to create a load spectrum covering, for example, 1000 flight hours. Thus to statistically analyze the load spectra of individual flights.

The cyclical nature of the loads on the structure is caused due to maneuvering, flight in a turbulent atmosphere, when upward gusts lead to a positive increase in g-forces, and downward ones - to a negative one and by roughness of the runway. A large contribution to the total fatigue damage of UAV’s structures is made by the enveloping flight loading cycle ground-air-ground (GAG), which is characterized by the highest loads that naturally occur once per flight [12].

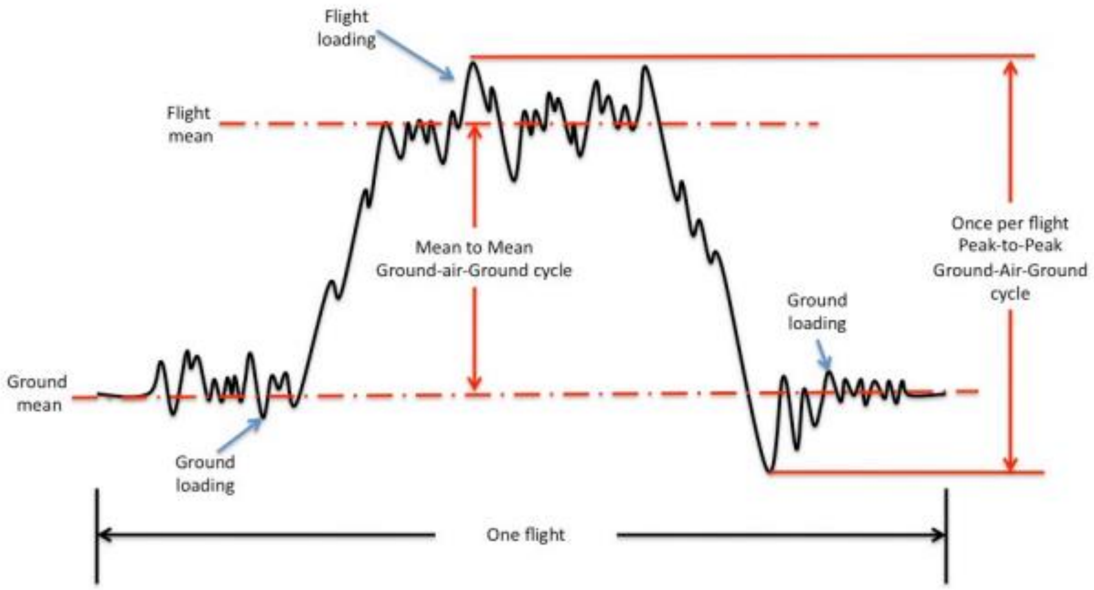


Figure. 2.14 Ground-Air-Ground Cycle Schematic

To calculate the maximum positive load of the GAG cycle, it is necessary to know the parameters of the integral repeatability of the damaging force factor (DFF) X for the flight. According to [13], the repeatability of vertical increments of overloads when exposed to vertical velocities of air gusts at the j-th stage of flight should be determined by the formula:

$$F_j = N_{0j} \cdot \tau_j \times \left[P_1 \cdot \exp\left(\frac{\Delta n_z}{b_1 \cdot A_w}\right) + P_2 \cdot \exp\left(\frac{\Delta n_z}{b_2 \cdot A_w}\right) \right], \tag{2.1}$$

where N_{0j} is the number of cycles to failure under regular loading at the j-th stage; τ_j is the flight time at the j-th stage; P_1 and P_2 are probabilities of flight in zones of moderate and intense turbulence, respectively; b_1 and b_2 are coefficients characterizing moderate and intense turbulence; Δn_z is vertical overloading (algorithm finding of which was presented in previous titles); A_w is the coefficient of the transfer function from vertical gust to overload, for each jth stage of a typical flight.

The integral repeatability of the overload increments per flight will be:

$$F_\Sigma(\Delta n_z) = \sum_{j=1}^{n} F_j\ (\Delta n_z)\ . \tag{2.2}$$

According to the recommendations [14] for detemination the GAG increment $\Delta n^{GAG}{}_{z\ max}$ of the maximum GAG cycle, it is necessary to take:

$$F_\Sigma(\Delta n^{GAG}_{z\,max}) = 0.694\ . \tag{2.3}$$

Then, the maximum overload value in the GAG cycle will be:

$$n_{z\,max}^{GAG} = 1 + \Delta n_{z\,max}^{GAG} \,. \tag{2.4}$$

As the minimum of the GAG cycle when the aircraft moves on the ground, a value proportional to the load in level flight is usually taken:

$$n_{z\,min}^{GAG} = -k \,, \tag{2.5}$$

Where k an is average coefficient. For UAV’s it can be taken as 0.5 (as well as for the light aircraft of the transport category [12]).

Then the equivalent value of the overload of the zero-load cycle corresponding to the current GAG cycle can be found by the Oding formula:

$$n_{z\,eq}^{GAG} = \sqrt{n_{z\,max}^{GAG} \cdot \left(n_{z\,max}^{GAG} - n_{z\,min}^{GAG}\right)} \,. \tag{2.6}$$

The equivalent stresses corresponding to the equivalent overload of the GAG cycle can be determined by the relation:

$$\sigma_{eq}^{GAG} = n_{z\,eq}^{GAG} \cdot \sigma_{HF} \,. \tag{2.7}$$

The stress in a structural element in horizontal flight, σ_{HF}, is a variable quantity due to the type and direction of the loads. The maximum turbulence of the atmosphere is observed at low altitudes, i.e. during the climb and descent phases. The highest stress in the structure corresponds to the climb stage, when the influence and value of the overloads are maximum. In this regard, with a certain margin, in calculating the damage from the GAG cycle it is necessary to we the value of the bending moment M_{X1} at the take-off stage, then:

$$\sigma_{eq}^{GAG} = M_{X1} \cdot \frac{S_p}{M_{X_p}} \,, \tag{2.8}$$

where S_p is stresses in the wing structure under the action of the bending moment M_{Xp} in static analysis.

The number of cycles to failure under regular loading with equivalent stresses of the GAG cycle can be determined by the formula:

$$N_{GAG} = \frac{A}{\left(\sigma_{eq}^{GAG}\right)^{m}} \,, \tag{2.9}$$

where A, m are parameters of the fatigue curve equation obtained experimentally.

Fatigue damage from a GAG cycle in one typical flight will be:

$$D_{GAG} = \frac{1}{N_{GAG}} = \frac{M_{X1}}{A} \cdot \left(\frac{S_p}{M_{X_p}}\right)^m \cdot (n_{z\,eq}^{GAG})^m \tag{2.10}$$

The total damage for a typical flight includes damage from accidental (random) loads D_{ran} and from a regularly repeating GAG cycle:

$$D_{\Sigma} = D_{GAG} + D_{ran} \, . \tag{2.11}$$

In some cases, depending on the structural design of the aircraft, fatigue damage to the structure can be added to equation (41) in ground operating modes.

The equivalent bending moment for the entire typical flight will be:

$$M_{eq} = \frac{M_{X_p}}{S_p} \cdot \sqrt[m]{D_{\Sigma} \cdot A} \, . \tag{2.12}$$

Durability of the structure in an amount of typical flights:

$$\lambda = \frac{1}{D_{\Sigma}} \, . \tag{2.13}$$

Design lifetime in an amount of typical flights:

$$T_{\lambda} = \frac{\lambda}{\eta_{\Sigma}} \, . \tag{2.14}$$

where η_{Σ} is standardized total reliability factor.

Lifetime in flight hours:

$$T_{\tau} = T_{\lambda} \cdot \tau_{HF} \, . \tag{2.15}$$

where τ_{HF} is typical flight time.

2.5. Conditions for laboratory life tests

The proposed algorithm departs from the typical tests for fatigue in the laboratory. However, there are a number of simplifications:

- technological limitations of certain software;
- small sample of parameters and data;
- imperfection of theoretical calculations.

For complete purity of the study, it is recommended to conduct the experiment under controlled conditions and after that compare it with given algorytm results.

Each of the types of tests is characterized by specific conditions for their conduct. Test conditions are a combination of mechanical, climatic and other influences that must be reproduced during tests to improve the strength and functional characteristics of the system, as well as a number of organizational, technical and technological procedures that must be implemented during the preparation and conduct of tests to ensure the possibility of using their results for registration of the corresponding design documentation.

2.5.1 Influences affecting the life characteristics

In laboratory life tests of complex structures and mechanical systems, the effect on the durability and functional ability of the following types of external influences is taken into account:

- the main external loads that come to the structure when moving along the airfield and in flight;
- the main functional loads acting in stationary modes of operation;
- the main functional loads acting in non-stationary modes of operation;
- additional external loads arising in the elements of mechanical systems during deformations of the main structure;
- additional functional loads arising from the elements of the system during asynchronous operation of the executive bodies, changing the control parameters, etc .;
- oscilation, vibration and impact loads;
- temperature;
- possible contamination of the lubricant or oxidation on open friction surfaces;
- other types of atmospheric influences, depending on the use of the main product and the degree of protection of the elements of the mechanical system from them.

The values of the listed influences are selected based on the technical problem, standards and other regulatory documents, taking into account the results of measurements in real operation. Each of these factors can affect the life of the main structure and mechanical systems to varying degrees. Those effects, the influence of which on the resource is significant, must be included in the typical load block of the test program.

Otherwise, this influence should be separately determined and taken into account when considering the test results and establishing the resource.

2.5.2 Typical load block. Forcing loads

A typical load block is an ordered set of actions applied to the test object, equivalent in damaging ability of a real set for the operating time that is reproduced by this block. The program block equivalently reflects a complex list of variable loads caused by aerodynamic and inertial loads in flight and at the aerfield.

Program blocks, as a rule, are made up for a fixed duration based on operating time or mileage in operation. If the values and number (action time) of loads, temperatures and other factors in the block are equal to their real actual or established reference values, then such a block is called non-forced.

Blocks in which the values of the influencing factors are higher, and the number of their repetitions (action time) is lower than the actual or reference values, are called forced and are used to reduce the test time, as well as in cases where the load of an unforced block cannot reveal the available safe live in the structure for example, when the number of loads per resource is more than 10^6 cycles and there is a endurance limit. In the case of object is loaded by vibration action, forcing can be achieved by increasing the load frequency compared to the operating one while maintaining or changing the characteristic operating unit of the load amplitudes.

When compiling program blocks, the following basic principles are observed:

1. In a typical block (between blocks), the extreme permissible values of impacts must be included with the frequency with which they can occur in real operation.

2. When forming a forced program block, from the range of operational loads, loads P are selected at such a level at which the damage to the structure ξ is maximum.

Note. a) Fatigue failure under load damage of the i-th level is:

$$\xi = P_{eq\ i}^{m} N_{ti}\ , \tag{2.16}$$

where P_i - equivalent reduced (to a symmetric or pulsating cycle) load of the i-th level; N_{ti} - number of repetitions of this load per unit of time; t - parameter of the slope of the fatigue curve.

b) Surface wear under load damage is:

$$\xi = P_i^m l(P_i)\,, \tag{2.17}$$

where P_i - the load of the i-th level; *l(P$_i$)* - the path traveled per unit of time under the load of the i-th level; t - parameter that depends on the type of friction and the range of load variation.

3. In the case when additional forcing of the load is required, its value may go beyond the actual values of the operating range, but at the same time it should not exceed the value that is maximum permissible for a given material, coating. And also the value from which the type of destruction can change under the action of a given load.

It should be taken into account that almost every destruction process has its own critical area, upon passing through which qualitative changes occur. The modes and methods of forced tests are chosen so that this critical area is not reached and, therefore, the qualitative aspect of the fracture process remains unchanged.

The equivalent E of the program block is calculated for each important and each potentially dangerous structural element. As the equivalent of the program for the entire object (system), the minimum of the equivalents is taken among those elements, the replacement of which is impossible in operation or, for some reason, is inappropriate. The equivalent of a program unit is defined as the ratio of the total (loads of all levels) damage rate for a given block during testing to the total damage rate per unit of time in operation.

$$E = \frac{\sum_{i=1}^{k} \xi_i}{\sum \xi_j} \left[{}^{block}/_{h}\right] \tag{2.18}$$

2.5.3 Conditions for conducting certification, periodic and type tests for UAV's

Certification and control periodic tests for fatigue resistance are carried out under block loading, including in full those types of effects that correspond to the expected (declared) operating conditions throughout the entire lifetime and affect the fatigue and functional characteristics of the structure and mechanical systems. The program block contains both typical and maximum permissible load modes. It also fully reproduces load spectra in operation at all critical points, taking into account the influence of various modes and load components, alos including the variable load scombinations and the of structural elements movement.

Control type tests for fatigue resistance are also carried out under block loading, including those types of actions that affect the lifetime and functional characteristics of the object with changes made to its design or manufacturing technology.

During the tests, the loading of the structure is continuously monitored according to the indications of calibrated strain gauges and dynamometers. For each critical point of the structure, the equivalents between the loading during testing and typical load spectra in operation are determined by appropriate calculation and / or according to the results of tests of structural samples.

Periodically, defectoscopy of the test structure is carried out by visual and instrumental methods. When inspecting, special attention is paid to the zones of the structure with a concentration of stresses, as well as to fixed and movable joints. If any structural element is destroyed or damaged during fatigue resistance tests, it is replaced or the damaged area is repaired. Before replacement (repair), after damage is detected, loading is carried out up to a certain acceptable number of cycles in order to study the duration of damage development. Tests are continuing to determine the life characteristics of other critical areas of the structure, and to verify the effectiveness of these repairs. In this case, the operating time of a replaced or repaired structural element is counted from the beginning of its tests, and the entire rest of the structure - according to the total volume of tests.

After the fatigue test, a residual strength test is performed. In addition to damage caused by fatigue testing, artificial damage is created, including partial or complete destruction of individual structural elements. The locations and degree of damage created during testing are determined depending on the specific type of structure, taking into account its testability and reliability of the means and methods for detecting damage in operation. In case of partial artificial damage, they provide a reliable simulation of the conditions at the ends of cracks, corresponding to their fatigue development under operating conditions. In particular, cracks are grown by applying variable loads. Corrosion damage to structural elements is imitated by mechanical damage. The level of equivalence of such a replacement in terms of residual strength is established on the basis of engineering analysis, relevant calculations, and test results. The damaged structure is loaded with an operating load, which is 67% of the maximum design load. In the event that there are damages in the structure that cannot be reliably detected with the current technical condition monitoring system, then the structure is loaded up to 100% of the maximum design loads.

At the end of the tests, the inaccessible zones of the structure and movable joints are disassembled for their fault detection. In doubtful cases, the material in the destruction zone is subjected to laboratory research.

Conclusion to part 2

Generally, to be able to determine effectively the UAV load spectrum it is necessary to increase the number of analyzed flights taking into consideration different scenarios, different weather and terrain conditions,, different pilots, etc. This would permit statistical analysis of occurrences of particular load increments. In Figure 2.12 there are two curves: the mean values and the values shifted up by 3 standard deviations. The latter curve takes into account possible dispersion of load increments occurrences (i.e. the number of appearances in relation to the flight times). On this basis it is possible to determine among other values the coefficients that should be applied for multiplication of the values existing in the HC-array compound from all analyzed flights in order to obtain more generalized results.

A method for calculating the fatigue damage of regular zones of the wing structure, taking into account the parameters of the profile of a typical flight at the design stage of the aircraft, is presented. The method is based on the industry accepted linear fatigue summation hypothesis and calculated fatigue life based on nominal stresses. The proposed method makes it possible to take into account the expected parameters of a typical flight at the aircraft design stage.

PART 3. LABOR PROTECTION

3.1 Features of work of users of computer technologies

The analysis, data processing and calculations related to the UAV resource are performed using computer technology.

Working with a PC radically changes working conditions and not always for the better [15]. The negative impact on human health during long-term work with computer technology is an objective reality. There is a direct link between the use of computer technology and many diseases (visual impairment, back and neck pain, pain in the wrists, elbows and shoulders, sleep disorders, chronic headaches, nausea, weakness, stress, skin diseases, congenital anomalies, provocation of epileptic seizures, strokes and other diseases). New diseases have emerged: the so-called computer vision syndrome and the Internet syndrome.

It is established that the state of the organism of the user of computer equipment depends on the type of work with the PC and the conditions of its execution. According to its complexity, the activity of computer users can be divided into three groups, although such a division is quite conditional, as this issue is not yet sufficiently developed and requires further detailed study.

Group 1 activity related to the performance of simple repetitive operations that do not require much mental effort. For example, the work of computer set operators, employees of reference services.

Group 2 activity related to the implementation of logical operations that are constantly repeated. For example, the work of a design engineer, automated production operator, etc.

Group 3 is an activity when in the process of work it is necessary to make decisions in the absence of a pre-known algorithm. For example, the work of a software engineer, railway traffic controllers, airports, etc.

In order to improve the working conditions of all three groups of users, it is necessary to organize their professional activities in such a way that in each group standard operations and creative components are combined as often as possible. Only in this case it is possible to optimize the level of nervous and emotional stress caused by the professional activity of computer users. The work of users of computer technology most often takes place in active interaction with other people, which, in turn, requires the solution of a range of issues that raise both psychological and socio-psychological aspects of labor relations. The latter, of course, is a factor that significantly affects the ability to work and human health, and this must be taken into account to ensure optimal working conditions for users of computer technology.

Negative effect on the visual organs

When working with a PC, the main load falls on the visual organs. Blurred images and flicker on the display screen have the greatest effect on the probability of visual impairment. The user may even get used to a slight flicker of text or picture, but the eyes automatically respond to this, straining the optic nerves and the corresponding visual centers of the cerebral cortex, and visual acuity is inevitably reduced. According to subjective estimates of operators, the critical frequency of light flicker, ie the highest frequency at which a person notices flicker, depending on the type of phosphor, screen resolution, image brightness, is about 70 Hz on modern displays.

As for PC users who wear glasses, they are more prone to visual impairments. This is because normal glasses usually require glasses other than those used by users to read.

Load on the musculoskeletal system

The work of any user of computer equipment is characterized by long, many hours of hard work in a monotonous sitting position. As a result, there is insignificant motor activity under significant local dynamic loads, which fall mainly on the palms of the hands. This nature of the work can lead to a number of painful symptoms. This is general fatigue, pain and numbness in various parts of the body (neck, back, arms, legs). The main functional disorders in the human body associated with the use of computer technology are diseases of tendons, muscles and nerve endings.

The occurrence of diseases of the musculoskeletal system of the hands contributes to: incorrect position of the body relative to the keyboard, deviation of the elbows from the torso, irrational mutual direction of the forearm and hands In Fig. 3.1 shows the incorrect and correct position of the hand and forearm relative to the keyboard.

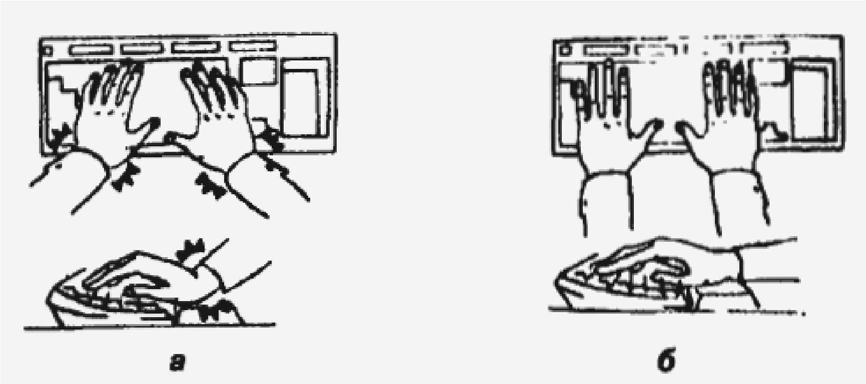


Fig. 3.1. Position of the hand and forearm relative to the keyboard: a - incorrect; b – correct.

It should be noted that not only work on the keyboard leads to disorders in the musculoskeletal system of the hands. The use of a device such as a "mouse" in the work also adversely affects the body of the user of computer equipment. By manipulating the "mouse", a person performs a large number of small movements of the same type, which leads to a constant load on the hand, forearm and shoulder. All this causes the appearance of unpleasant and later painful sensations in the wrist, elbow and especially shoulder joints.

In fig. Figure 3.2 shows the correct and incorrect position of the hand and forearm when working with a "mouse" device.

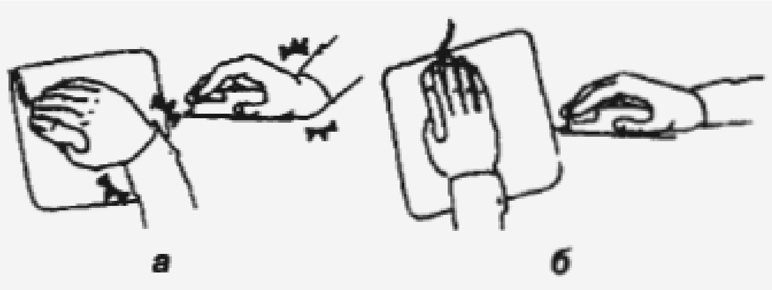


Fig. 3.2. The position of the hand and forearm when working with device type "mouse": a - incorrect; b – correct.

Thus, it can be stated that the main overstrain of the musculoskeletal system of man when working with computer technology is caused primarily by many hours of hard work in a monotonous sitting position, and therefore limited general motor activity (hypodynamics), as well as which exist when working with the keyboard and the device type "mouse".

Information and intellectual overload. Nervous and emotional stress

They have the greatest negative impact on the health of computer users, in particular on the work of their cardiovascular and central nervous systems.

The main condition under which intensive intellectual activity of a person begins to cause significant and persistent disturbances in the work of his cardiovascular system is a simultaneous decrease in its motor activity, which occurs during the work of computer users.

The most common type of disease among computer users is mental fatigue, which is accompanied by the following symptoms: reduced ability to perceive information and the ability to concentrate; slowing down of thinking; decreased ability to remember; abrupt changes in emotional state; depression, irritability or loss of emotional balance; slowing down sensorimotor functions.

The main reason for the development of emotional tension among computer users is the need to process a large amount of information in conditions of lack of time and high motivation for work. Emotional tension is usually accompanied by activation of the nervous system and the appearance in the blood of biologically active substances that change the activity of the circulatory system, respiration, digestion, etc. This is a kind of protective reaction that occurs in the human body in response to adverse external factors, and it is called stress. There are three phases of stress: anxiety (mobilization of protective forces), resistance (adaptation to difficult conditions), exhaustion (under prolonged stress). The last phase often leads to neuroses. The main symptoms of neurosis are reduced efficiency, indifference to the environment, lack of any interests. The person becomes restless, inattentive, coordination of movements worsens. Neuroses are characterized by such symptoms as sleep disturbance, headache, sudden mood swings, feelings of helplessness.

3.2 Sanitary and hygienic requirements for working conditions at computerized workplaces

Equipment and organization of the workplace with PC must ensure compliance with the design of all elements of the workplace and their mutual location to ergonomic requirements, taking into account the nature and characteristics of work (DSTU 8604: 2015, DSTU 7299: 2013, DSTU 7951: 2015) [16].

The design of the PC user's workplace should ensure the maintenance of optimal working posture.

PC workstations should be positioned relative to the light slots so that natural light falls on the side, preferably on the left.

The following distances should be observed when placing workbenches with a PC: between the side surfaces of the PC - 1.2 m; from the back surface of one PC to the screen of another - 2.5 m.

The PC screen should be located at the optimal distance from the user's eyes, which is 600 ... 700 mm, but not closer than 600 mm, taking into account the size of alphanumeric characters and symbols.

The location of the PC screen should provide the convenience of visual observation in the vertical plane at an angle of + 30° to the normal line of sight of the worker.

The keyboard should be placed on the table surface at a distance of 100...300 mm from the edge facing the worker. The design of the keyboard should include a support device (made of a material with a high coefficient of friction, which prevents its involuntary displacement), which allows you to change the angle of the keyboard surface within 5…15°.

To ensure protection and achieve standardized levels of computer radiation, it is necessary to use screen filters, local light filters (personal eye protection) and other means of protection that have been tested in accredited laboratories and have an annual hygienic certificate.

When equipping the workplace with a PC laser printer, the parameters of laser radiation must meet the requirements of [17].

3.3 Requirements for preventive medical examinations

Workers with PC are subject to mandatory medical examinations: preliminary

- when hiring and periodic;
- during employment in accordance with [18].

Periodic methodological examinations should be conducted every two years by a commission consisting of a therapist, neurologist and ophthalmologist.

Doctors of other specialties may be involved in the examination of the commission that conducts preliminary and periodic medical examinations, if necessary (if there are medical indications).

The main criteria for assessing the suitability for work with PC should be indicators of the state of the visual organs: visual acuity, refractive index, accommodation, the state of the binocular apparatus of the eye, and so on. It is also necessary to take into account the state of the organism as a whole.

Women who work with a PC must be examined by an obstetrician-gynecologist once every two years. Women from the time of pregnancy and breastfeeding are not allowed to perform all work related to the use of PC.

Compliance with the requirements set out in the Rules, in combination with the practical implementation of primary and special measures should become the norm for all professionals directly related to training and production teams.

Conclusion to part 3

Work related to the use of electronic computers is a potential source of harmful and dangerous production factors that have a negative impact on the health of the employee.

Systematic exposure to factors such as microclimatic conditions, light levels, noise levels, high voltage, etc. that do not meet standards increases the risk of diseases of the visual, musculoskeletal and nervous systems and increases the overall level of occupational disease. Thus, timely detection and analysis of dangerous and harmful factors of PC user production is a necessary condition to prevent the negative consequences of their impact.

This section discusses and identifies the working conditions in which PC users typically work. Requirements for the organization of the workplace and requirements for preventive medical examinations are specified.

PART 4. ENVIRONMENTAL PROTECTION

The extent of environmental harm to drones much smaller compared to similar effects of machine devices that have long been known to users. On the other hand, the availability of all-accessible UAVs often goes hand in hand with the impossibility to use them properly. As the technique is quite new, it arouses the interest of users and quickly gains popularity, respectively - quickly sold. And as is often the case, the introduction of UAVs has also caused some negative aspects, especially for the environment.

The damages of drones on the environment include increased level of urban noise, damage and death of nature species at the time of drone flights and disasters, and an increased amount of environmental waste, that is an evitable result of gadget upgrades and new battery technologies.

The regulations of drone usage quickly adapted the commercial availability of drones, and many institutions responded quickly to issues and concerns that people collided during the regulation-free exploitation of drones. Now, there cannot be an excuse for not following the regulattions on drones in the current country.

4.1 Noise

Drones cause a very significant noise level during operation time. In addition, there is a correlation between the distance from drone to the observer and the noise level. Decibel (dB) is the logarithmic unit of sound, ie it increases by the power of 10 for each unit increase [19] It is necessary to understand on what scale noise is classified to fully understand the impact on human.

Table 2. Noise leven gradation

dB level	everyday example	UAV type
10	normal breathing	
20	watch ticking	
30	whispering nearby	
40	quiet library	
50	refrigerator working	Small fixed-wing
60	quiet traffic noise	Small rotor

End of a Table 2

70	washing machine working	Large quadcopter
80	morning alarm clock	Large fixed-wing
90	subway train	
100	machinery/pneumatic drill	
110+	car horn/jet engine from about 100 m	

The noise level over 140 dB over a short period is considered dangerous to the human hearing, and and at the same time noise level over 85 dB over a long period of time will also be dangerous to the human ear.

For example, series rotor drones (mainly category "A") produce noise in the range of 70-80 dB. The reason for such noise is that propellers move quickly that displace air, causing pressure to rise and fall as the UAV moves. This is a reason of characteristic noise during the drone flight.

As UAVs are now considered as a means of delivery, entertainment, photography and video in urban environments, air congestion made by the drone usage can cause an increase in noise pollution in urban areas. Fortunately, there are ways to reduce noise from the rotary drones, such as noise absorption, using more propellers with lower rotational speed, and usage of low-noise propellers.

At present, ICAO is closely monitoring the development of the industry and has not issued relevant regulations to limit the drone exploitation. However, due to conflicting perceptions, the public and the community perception of this technology varies from person to person. In general, society believes that it can tolerate the noise of its own drones. While the noise made by entertaining UAVs used for social benefits may be unacceptable. Typically, heavier and larger industrial UAVs will make more noise, so it is safe to assume that in the future the public will pay more attention to international noise standards when large passenger UAVs operate in urban areas.

4.2. Wastes

The increased demand of product causes new quantity of production and operational waste. Firstly, the plastics and composite materials that are used in drone airframe technology. And secondly, the consumables in a form of lithium polymer batteries and electronics. Both of the forms must be recycled in the best-case scenario.

Also an amateur using a drone can often lose it in various ways: bad piloting, bad signal or signal loss etc. The drone can get entangled in tree branches, fall in the water, lost in a dust storm and etc. Also when in the natural environment drone can decompose for an indefinite period of time without supervision and control.

Electronics

The amount of e-waste was increased by more than 20% in five years and became 53.6 million tonnes [20]. With no proper recycling, there is no doubt that e-waste will cause a significant amount of landfills that can be source of the toxicity. In general, there are problems with recycling infrastructure to handle electronic waste in a number of countries.

In 2019, the Global e-Waste Statistics Partnership found [20] that America collected only about 9% of its e-waste. Asia in the year generated the largest amount of e-waste - 24.9 million tons with an official level of collection and recycling of only 11.7%.

No research has been conducted to determine what is a drone input in this statistics, but in future drone will add its big part to the waste statistics. As companies such as DJI, Parrot and Autel produce new drone models every couple of years, there is no doubt that the amount of electronic drone waste will increase in the coming years.

Lithium polymer batteries

According to a 2016 study [21], lithium polymer batteries held about 17.6% of the market share.

This study also emphasizes that there are two ways to recycle lithium polymer batteries - using a pyrometallurgical approach and a hydrometallurgical approach. Other countries have developed systems to use these two lithium polymer batteries recycling methods.

This means the lithium there is recycled by using fire and water to dissolve or separate recyclable components from things like plastic, which is commonly used as a substrate for printed circuit boards.

Plastic

With rapid growth on drones demand, the amount of plastic dropped by the drone in terms of accessories and propellers is also increased. The positive here is a study that was published in 2018 [22] that explored possibility of using recycled plastic from bottles like PET as filament for 3D printing.

This means the drone body can be redesigned using 3D printing. The study offered a cheap way to recycle plastic and create a drone glider that can stand rainfall, splashes of water, stress and strain during flight.

The household advices for wise users:

- dispose of the battery only in approved recycling containers after a complete discharge;
- do not dispose of the battery in ordinary trash cans;
- strictly meet local requirements on disposal and recycling of batteries.

If the Intelligent Flight Battery On/Off button is disabled and the battery cannot be fully discharged, a professional battery utilizing/recycling agent for further assistance should be involved.

4.3. Impact on flora and fauna

The trend suggests that users like to use drones in the most bizarre areas of the planet, to study ecosystems that have not previously been easily investigate.

Animals react differently to drones. First of all, they perceive them as something foreign, as a threat, and the abnormal noise level amplifies the effect. This causes fear, followed by the following two reactions:

a) an escaping;

In addition, drones can have a destructive effect on nests, burrows, hiding places where animals live. As a result - the animal leaves its own environment, gets lost in space, leaves the herd. Cubs lose their nursing females and are unable to survive. This can harm populations in a global sense.

b) an attack during which a creature may be injured or even die.

When attacking a drone, an individual may collide with propellers that rotate at high speeds. Research [23] shows that it is not only superficial wounds, but also bone injuries, if the propeller blades are made of quality plastic or composite materials.

There is also the possibility of a sudden collision of UAVs in the air with birds.

In accidents or catastrophes, UAVs can cause forest fires that destroy entire ecosystems. Animals burn, get numerous scorches or suffocate due to the abnornous quantity of carbon dioxide. Flora also suffers, usually it is hard to know for sure what percentage of plants disappears. If these are still hard-to-reach natural areas, it is very complex and problematic to put out a fire as soon as possible.

If the UAV operation is carried out over water, then in a catastrophe, falling into the water, it can be swallowed by large fish.

Conclusion to part 4

There is still space for the negative influence of UAVs on the environment. Most of the mentioned above problems can be referred to the human factor.

This means that all owners and users should take responsibility for competent piloting, timely maintenance and efficient recycling, as well as being ecologically conscious when disposing of old or broken drones. With technology development, it is possible to obtain more recyclable materials from different parts of the drone such as electronic components or lithium polymer batteries. After this the negative impact of drones wastes on the environment will be greatly reduced.

It is also important to be careful when planning and carrying out animal observation missions. Particular care should be taken when studying rare and endangered species.

The noise level should be reduced as much as possible, based on regulations and the will of the public.

GENERAL CONCLUSION

There are more and more civilian UAVs every year. The idea of a classic military drone recedes into the background. A characteristic feature of the use of drones is the variety of tasks they can perform. Many areas of human life are actively implementing them to carry out numerous tasks. However, as the number of UAVs increases exponentially, so should the responsibility for the design and application approach. Design and operational features must be met, both at the design stage and in expluatation.

To this end, new certification rules must be introduced, taking into account appropriate, rigorous and comprehensive classification. EASA is actively working to ratify the requirements on the basis of its own division, based on potential operational risks, drone mass and objectives.

Conclusions from normative documents show that weight as a complex indicator is the main criterion that determines the strictness of certification. The heavier the aircraft, the higher the requirements for it and safety: if the weight is up to 750 kg, it is better to use VLA requirements, if less - the conditions described by the manufacturer and the competent authority in a particular country.

An algorithm for determining the load spectrum was proposed above, which plays an important role in determining the fatigue characteristics of UAVs. The data obtained from the test flight and tlog, and its analysis by specific scientific methods allow to determine the load range for different weather conditions and the type of piloting.

The next step is a comparison the calculated integral repeatability of overloads and equivalent bending moments with the results of UAV data processing, and matching the numerical and experimental data. Controlled experiments contribute to this. If the results of calculating fatigue damage to a structure based on overloads at the center of gravity of the UAV do not differ significantly from the calculation based on equivalent bending moments in different wing sections, then this will further make it possible to work with any type of DFF in flight using a continuous atmospheric turbulence model. The developed method can be taken as the basis for the methodology for assessing the design, consumed and residual life of the structure, taking into account the actual history of the UAV operation.

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