XVI International Student Conference
"INTELLIGENCE. INTEGRATION. RELIABILITY."

Book of theses

NATIONAL TECHNICAL UNIVERSITY OF UKRAINE
"IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE"

Educational and scientific Institute of Aerospace Technology

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“INTELLIGENCE. INTEGRATION. RELIABILITY”

BOOK OF THESES

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UDC 629.7

Bakun V., Marynoshenko O.

USE OF GAS-EJECTOR INSTALLATIONS IN ROCKET ENGINE TEST STANDS

Introduction. Testing in vacuum chambers is a key stage for studying rocket engines in rarefied atmosphere conditions, which are significantly different from the terrestrial environment. Such experiments allow us to assess whether the engine will operate stably at a "minimum level of back pressure at the outlet" [1], and at the same time minimize the risks of such undesirable phenomena as "overheating or thrust instability" [2]. Vacuum support systems installed on modern test stands are of critical importance, as they create a "rarefied atmosphere that simulates outer space" [3]. This allows us to test the technical characteristics of the engine, in particular the efficiency of fuel combustion and stability of operation. Tests in conditions as close to space as possible provide an accurate analysis of the engine's operation and open up opportunities for its further improvement.

Statement of the main materials of the study. Typical design solutions for creating conditions close to vacuum usually include a combination of mechanical pumps of various types and equipment that implements the self-ejection effect. This is due to the fact that one method for rarefaction of the medium is often not enough. Mechanical pumps operate on the basis of physical displacement of gas from the working volume of the vacuum chamber. These are one of the simplest and most affordable vacuum systems, which are mostly used to achieve low or medium vacuum [4]. They are divided into several types:

- Piston pumps provide gas displacement by periodic compression and expansion. These pumps are characterized by power and reliability, but have relatively low productivity.

- Spiral pumps use a pair of spirals that rotate relative to each other, gradually moving the gas outward. They operate quietly and efficiently, but are not able to create a high vacuum [5].

To create a preliminary rarefaction of the medium, one of the most common solutions is the use of water-ring pumps. They are used on test stands for liquid rocket engines, especially for preparing the vacuum chamber before further pressure reduction. The principle of operation of a water-ring pump is to rotate the rotor inside the housing, partially filled with liquid. During rotation, a ring of water is formed, which creates variable volumes between the rotor blades [6]. This allows gas to be captured at the inlet, transported to the outlet and gradually displaced from the system, ensuring the achievement of a relatively low vacuum.

The main advantages of water-ring pumps [7]:

- Reliability and simplicity of design, which reduces their susceptibility to wear.

- Resistance to aggressive environments, since the water ring protects the mechanism from contact with gases.

However, they also have disadvantages:

- Limitation in achieving only an average vacuum level.

- Decrease in efficiency at very low pressure levels.
- The need for water supply and cooling, which increases operating costs.

Due to these limitations, water ring pumps are often used as part of combined systems, where they perform the initial pressure reduction. To achieve a deeper vacuum, other types of pumps or installations that implement the self-ejection effect are used. On test benches for liquid rocket engines, the self-ejection effect contributes to additional rarefaction, creating conditions that are as close as possible to space ones.

Conclusions. In order to ensure the operability of the test bench, it is possible to use gas-ejector installations. These installations can be used to provide a high degree of rarefaction of the working medium, provided that they are implemented in multiple stages.

References:

1. Gao, M., Zhang, L., Zhang, D., & Zhang, L. (2019). Experimental study on the enhancement of free convection heat transfer under the action of an electric field. Experimental Thermal and Fluid Science, 104, 9–14. https://doi.org/10.1016/j.expthermflusci.2019.02.006

2. Huang, D. H., & Huzel, D. K. (1992). Modern engineering for design of Liquid-Propellant rocket engines. https://doi.org/10.2514/4.866197

3. Dreyer, M., Braucker, R., & H, K. (2012). Design and development of test benches for rocket propulsion systems. Propulsion and Power Research, 4(1), 210–218. https://doi.org/10.1016/j.jppr.2012.09.004

4. Dharavath, M., Manna, P., & Chakraborty, D. (2015). Numerical exploration of mixing and combustion in ethylene fueled scramjet combustor. Acta Astronautica, 117, 305–318. https://doi.org/10.1016/j.actaastro.2015.08.014

5. St-Onge, D., Sharf, I., Sagnières, L., & Gosselin, C. (2017). A deployable mechanism concept for the collection of small-to-medium-size space debris. Advances in Space Research, 61(5), 1286–1297. https://doi.org/10.1016/j.asr.2017.12.026

6. Gao, M., Zhang, L., Zhang, D., & Zhang, L. (2019b). Experimental study on the enhancement of free convection heat transfer under the action of an electric field. Experimental Thermal and Fluid Science, 104, 9–14. https://doi.org/10.1016/j.expthermflusci.2019.02.006

7. Thomas, A., & Smith, R. (2020). High-altitude simulation in rocket testing: Methods and applications. International Journal of Aerospace Engineering, 1–11.

UDC 62-112.83

Cilo Z. N., Ortamevzi G.

STREGTH ANALYSIS OF RIM BOLT OF THE MAIN LANDING GEAR

Introduction. In this study, the strength of the bolts was analyzed according to the pressure that would occur on the main landing gear rim of an experimental aircraft according to the hardness of the landing, using the finite element method. A 3D model and mathematical model were created for the rim of the main landing gear, and different physical situations were simulated depending on the increase in air pressure in the tire. The use of bolts used in the assembly of rim parts was analyzed through the Mathematical Model. Analysis outputs, stress and safety factor values were compared. [1][2][3][4]

Materials and methods. A 3D model of the two-piece rim parts of the main landing gear and the bolts used in the assembly of the rim parts were created. The 3D Model is shown in figure 1.

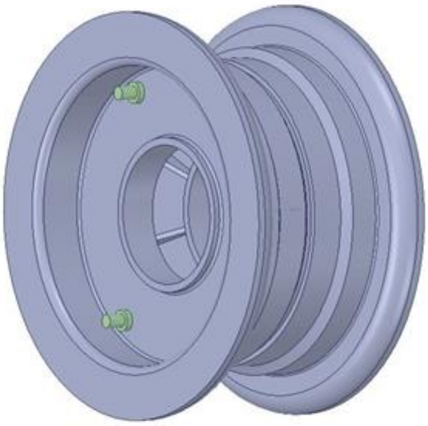


Figure 1 - 3D Model

Mathematical models were created to perform strength analysis of these parts using finite element methods. Since the bolts are small in size compared to the rim parts and the bolts are the focus of this study, they were frequently meshed when creating mathematical models.[5][6] Mesh statistics of mathematical models, 1,233,138 nodes and 721,071 elements for total assembly. Mathematical models are shown in figure 2.

Figure 2 - Mathematical Model

During aircraft landing, the weight of the aircraft and the impact damping of the tire will increase the air pressure inside the tires. Pressure will be transmitted to the rim from the rim seating surfaces of the tires. This pressure will determine the bolt thickness and number of bolts. In this study, it is assumed that the pressure value for both tire seating surfaces on hard landings is 1.25MPa in total. The bolts holding the left-side and right-side rim parts together will be subjected to tension. In addition, the situation of nut loosening due to vibration or insufficient torque was also analyzed.

Results and Discussion. The drive side of the rim was fixed and 1.25 MPa pressure was applied to the non-drive side, thus simulating the tire pressure that would occur during the landing of the plane. After this simulation, the stress and safety factor states of the bolts of the rim mounted with a total of 3 bolts were analyzed. After this simulation, the stress and safety factor states of the bolts of the rim mounted with a total of 3 bolts were analyzed. The safety factor is inversely proportional to the stress distribution, around 1 on the bolt and nut sides, and around 1.9 on the bolt body. Stress and safety factor distributions for bolts are shown in Figure 3 and Figure 4.

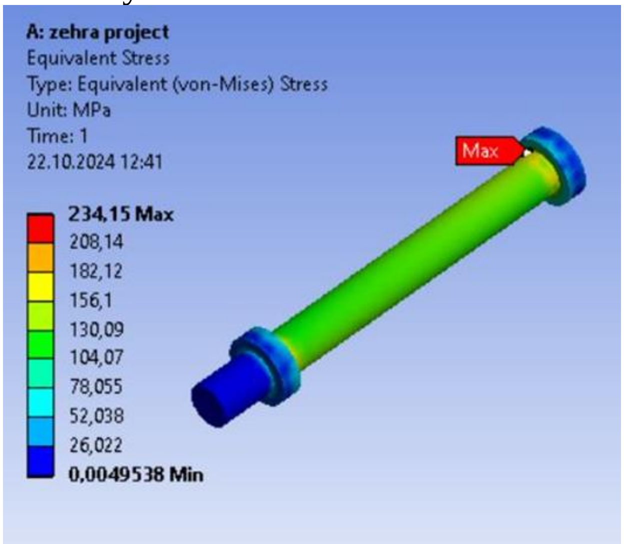


Figure 3 - Stress bolt

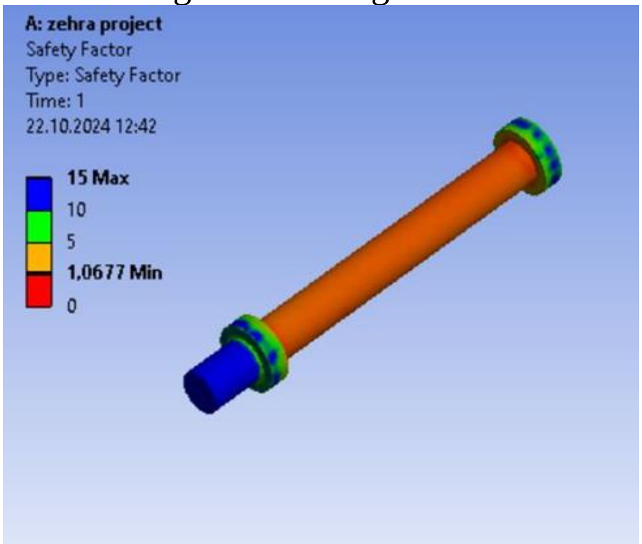


Figure 4 - Safety Factor of rim bolt

Conclusion.

1. Since the bolt area inside the rim is exposed to high tensile stresses, the threaded structure in the body of the rim mounting bolts should not be in the remaining part inside the rim. Since this gear structure will cause stress concentration at the tooth bottoms in areas where tensile stress exists, rupture may occur.
2. High stress of the bolt area inside the rim may indicate an increase or decrease in incorrect bolt tightening torque. If the bolt is over-tightened, it will cause too much stress on itself, while if it is under-tightened, it will put too much stress on the neighboring bolts.[7] Therefore, bolt tightening torques must be equal and at appropriate values for each bolt.
3. Nut loosening due to vibration is very important for rim bolts. If the nut loosens on a bolt, other adjacent bolts may be exposed to high stress and break. Therefore, reliable precautions must be taken to prevent the rim bolts from loosening.

References:

1. J.-M. V. Vugampore, “Development of high strength material for smart aircraft bolt.,” Citeseer, 2005.
2. S. Liu, J. Chu, and Y. Wang, “Research on Prediction Method of Bolt Tightening for Aviation Components Based on Neural Network,” *Appl. Sci.*, vol. 13, no. 11, p. 6771, 2023.
3. I. K. Giannopoulos, D. Doroni-Dawes, K. I. Kourousis, and M. Yasaee, “Effects of bolt torque tightening on the strength and fatigue life of airframe FRP laminate bolted joints,” *Compos. Part B Eng.*, vol. 125, pp. 19–26, 2017.
4. D. J. Porter, Flight failure: Investigating the nuts and bolts of air disasters and aviation safety. Rowman \& Littlefield, 2020.
5. D. Zeren, F. Kocatürk, and M. B. Toparli, “Performing Mechanical Strength and Torque Studies for Weight Reduction in Norm One Way Patented Product,” *Orclever Proc. Res. Dev.*, vol. 1, no. 1, pp. 142–151, 2022.
6. Y. Sun, O. G. Grebenikov, and C. Li, “Analysis of force distribution of four rows of bolts in aircraft fitting joint,” *Int. J. Aerosp. Eng.*, vol. 2021, no. 1, p. 9962645, 2021.
7. S. Erim, *Fatigue of bolts in tension*. University of Bath (United Kingdom), 1981.

UDC 629.765

Danylchenko D.

REDUCTION METHOD OF SPACE DEBRIS USING A REUSABLE SPACE PAYLOAD UNIT

Statement of the problem. The problems of "space debris" were first identified in the 2000s, and as a solution to these problems, decisions were made from changing the operating height of the orbit for commercial satellites to creating standards [1] and restrictions for launch companies and developers of spacecraft. However, the first dated damage was caused by a 1 mm particle on a space shuttle porthole back in 1983. Since that time, the number of space debris objects has grown exponentially and continues to form new elements due to the collision of parts of launch vehicles or spent or existing satellites.

According to NASA, the number of objects in Earth's orbit has been recorded at about 26,000 "space debris" larger than 10 cm. Each small or large object poses a threat to the safe operation of existing and new satellites.

The main part. The following methods for removing "space debris" are considered:

- shooting of "space debris" with a laser from the surface of the Earth [2];
- use of a satellite "guard" [3];
- the use of a a solar-powered propellantless space vehicle [4].

Most of these methods are at the development stage and have full-scale models, but these methods have not been widely implemented.

The disadvantages of existing methods are summarized in Table 1.

Table 1. Disadvantages of existing methods

	Existing methods		
	Shooting of "space debris" with a laser	*A satellite "guard"*	*A solar-powered propellantless space vehicle*
Creation of new objects	Yes. Each knocked down object will create smaller objects	Yes. After completing the mission, the devices leave orbit for 3.5 years	Not known. This method is expensive and only at the idea stage
Expensiveness	No. No need to launch this system into space	Yes. Increasing the cost of each launch mission due to the need to launch an additional satellite	Yes. The need for maintenance and repair

Efficiency	No. As long as large objects are removed, small ones will continue to destroy	Yes, but only for one object within the mission	Yes. Using the hand of the manipulator, large and small objects can be removed, and the nets will collect small ones

Based on the analysis of the existing methods of cleaning the Earth's orbit, it is proposed to use both reusable space main parts for the rescue of disabled spacecraft and for the simultaneous removal of "space debris" from the Earth's orbit. It is proposed to change the structural design of the space main part and add harpoons, nets or magnetic traps and an additional amount of fuel to equalize speeds to its composition.And it is also proposed to change the withdrawal program and add additional movement to capture and remove "space debris", and if necessary, return to the Earth's surface with a disabled expensive spacecraft for recovery and relaunch.

Conclusion.

1. Each launch mission will perform the tasks of putting spacecraft into orbit and removing not only its own systems, but also additional objects.
2. Reducing the cost of removing space vehicles due to the performance of additional missions to clean the Earth's space.
3. Cleaning the Earth's orbit with each launch mission.
4. The formation of new space debris objects by our own systems is decreasing.

References:

1. NASA-HDBK-8719.14. Edition. Handbook for Limiting Orbital Debris. [Effective from 30.07.2008]. [Electronic resource] https://standards.nasa.gov/standard/nasa/nasa-hdbk-871914
2. Frank Landymore, Startup Building Huge Laser to Shoot Down Space Junk From the Ground. URL: https://futurism.com/the-byte/ground-laser-shoot-down-space-junk (publication date: 17.01.2024).
3. Astroscale’s ELSA-d Finalizes De-Orbit Operations Marking Successful Mission Conclusion. URL: https://astroscale.com/astroscales-elsa-d-finalizes-de-orbit-operations-marking-successful-mission-conclusion (publication date: 24.01.2024).
4. Pearson, J., E. Levin and J. Oldson. ElectroDynamic Debris Eliminator (EDDE): Design, Operation, and Ground Support. THE AMOS CONFERENCE. Conference. URL: https://amostech.com/TechnicalPapers/2010/Posters/Levin.pdf (conference date: 14-17 sep. 2010).

UDC 62-4

Danylenko V., Lipovskyi V.

THE PROBLEM OF AGING OF ADDITIVELY PRODUCED THERMOPLASTIC AEROSPACE DETAILS

Introduction. Polymers play significant role in modern world. Their prominent properties, such as lower density, higher specific strength and stiffness, design flexibility, enhanced vibration and noise dampering, reduced thermal expansion, cost efficiency for high-volume production defined its increasing use as aerospace construction material.

Additive manufacturing (AM), and 3D printing specifically, enhances flexibility of thermoplastics, allowing to produce highly efficient detail configurations as parts with low infill (~15%), sandwich honeycomb cores, fiber-reinforced composites, etc.

Statement of the problem. Although, relative to metals thermoplastics exhibit higher corrosion resistance, their properties degrade after long exposure to aggressive environment. Ability to predict these changes at laboratory research stage would increase reliability, safety, and economy of future designs. Both mechanical testing and computer modeling can provide valuable insights into this problem.

Statement of the main materials of the study. Environment can cause several types of defects, such as cracking, hardening, softening or other surface damage. It is due to polymers susceptibility to oxidation and degradation processes. Degradation is a process of structural changes caused by long-term physical or chemical factors (water vapor, heat, oxygen, UV and other radiation, dynamic loads), and results in reduced structural properties. The most typical case of simultaneous action of several factors is atmospheric aging.

Exposure time, polymer type, technological process, geometry will affect the rate of aging. For example, crystalline polymers are more resistant to degradation than amorphous ones.

Although, this process can improve properties of the detail when induced intentionally and under control (i.e. tempering,), uncontrolled it can reduce parts life cycle drastically.

Natural aging may take years, so to assess the life of thermoplastics in lab degradation processes are sped up. Aging processes typically accelerate with temperature increase. The relationship between the rate of degradation and temperature can be found empirically. This allows to estimate the degradation level after a certain time.

There are different methods of lifetime prediction of degradable polymers using accelerated ageing tests and methods for extrapolation of data from induced thermal degradation: the Arrhenius model, time–temperature superposition (TTSP), the Williams–Landel–Ferry (WLF) model and 5 isoconversional approaches: Friedman’s, Ozawa–Flynn–Wall (OFW), the OFW method corrected by N. Sbirrazzuoli et al., the Kissinger–Akahira–Sunose (KAS) algorithm, and the advanced isoconversional method by S. Vyazovkin. Each of them has its advantages and disadvantages.

Validation of applicability of these models to 3D printed polymers aging require additional research.

Another important element in development of experimentally proved models is establishing standards for testing of additive manufactured polymer components. Existing testing methods for plastics, for example ISO 527-2, focus on moulded, extruded, and cast materials. Fused Deposition Method (FDM) parts, however, are additively manufactured using a layer-by-layer deposition method, which is neither a moulding, extrusion, nor casting process in the traditional sense. Moreover, FDM printed parts with low infill (e.g., 15%) typically have internal lattice structures or air gaps, making them structurally different from solid moulded, extruded, or cast parts. ISO 527-2 primarily applies to solid samples and does not specifically address the unique structural properties introduced by low infill.

One of the possible solutions that would complement and potentially substitute expensive lab testing is development of an Finite Element Analysis (FEA) methodology to approximate the environmental aging of 3D-printed parts. The inputs for such methodology will include technology, material type, brand of material, infill, layer height, infill pattern, section area, orientation. The usual ways that FEA are employed may not be applicable due to the inherent anisotropy, possible complex designs, and uncertain qualities of 3D-printed parts. FEA can no longer accurately predict the behavior of 3D-printed parts, in the same way FEA estimates the behavior of parts produced by traditional methods. What adds to the complexity are the different AM methods and the lack of test results using these printing methods and therefore very few strength data. It would require creating a database, which compares different printing materials and parameters to analyze the mechanical characteristics of 3D-printed parts. Simplified models can be adopted, and assumptions be made to simulate the mechanical properties of 3D-printed parts, but the approximations will not be very realistic. For 3D-printed parts to be adopted at an industrial level, AM techniques must demonstrate that these parts meet structural and mechanical standards.

Conclusions. It is important to explore how 3D printed thermoplastics features affect applicability of existing models of accelerated aging.

Environmental testing combined with finite element modeling will significantly improve the quality of future aerospace 3D printed parts.

References:

1. Plota, A. and Masek, A. (2020). Lifetime Prediction Methods for Degradable Polymeric Materials—A Short Review. *Materials*, 13(20), p.4507. doi:https://doi.org/10.3390/ma13204507.

2. Dizon, J.R.C., Espera, A.H., Chen, Q. and Advincula, R.C. (2018). Mechanical characterization of 3D-printed polymers. *Additive Manufacturing*, 20, pp.44–67. doi:https://doi.org/10.1016/j.addma.2017.12.002.

3. International Organization for Standardization (2012). Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics. [online]Available at: https://www.iso.org/standard/56046.html

UDC 629.7.01

Durmus S., Ortamevzi G.

STRENGTH OF MAIN LANDING RIMS ACCORDING TO HARD LANDING SITUATIONS

Introduction. In this study, the strength of the main landing gear rim of an experimental aircraft was analyzed in landing situations using the finite element method. A 3D model and mathematical model were created for the rim consisting of two parts belonging to the main landing gear.[1][2][3] The impact condition of the rim was simulated using this mathematical model and the strength, stress and safety factor parameters of the rim were determined.

Materials and methods. A 3D model consisting of the right and left rim parts of the main landing gear of the experimental aircraft was created in order to analyze its strength against impacts during hard landings.[4] The 3D model is shown in Figure 1.

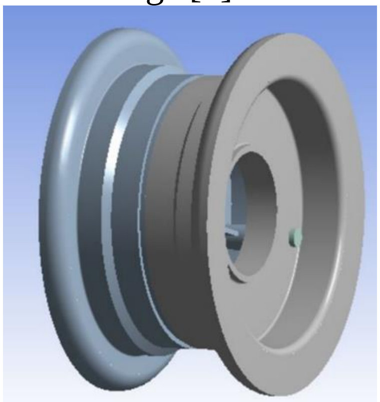


Figure 1 - 3D model of rim

Mathematical models of the relevant parts were created using the finite element method in order to apply the impact forces that will occur in hard landings and to determine the stress and safety factor values. The mesh statistics of the mathematical models consist of 1237796 nodes and 723809 elements for the entire rim. Mathematical models are shown in Figure 2.

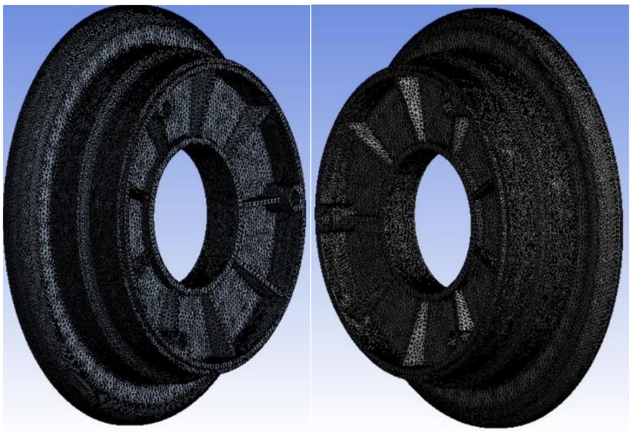


Figure 2 - Mathematical model of rim

The materials of these parts were selected as stainless steel for strength and corrosion protection.[5] Since the rim will be exposed to ground load during landing and the weight of the aircraft will interact with a higher G factor than the gravity acceleration, the impact load will be applied to the underside of the rim. In this analysis, the predicted loads were applied to the underside of the rim in order to simulate this situation.

Results and Discussion. The impact that the rim receives from the contact area of the runway during hard landings was simulated 6000 N as remote force as extreme. As a result of this simulation, stress was observed in the contact area and the rim ribs just the opposite. The stress values in the area were especially concentrated in the rib corners and were observed as a maximum of 45 MPa. The tire seating surfaces in the contact area were around 33 MPa. Safety factor values ranged between 5-8 in the light of these stress values, which are not very high. Stress and safety factor distributions are shown in Figures 3 and 4.

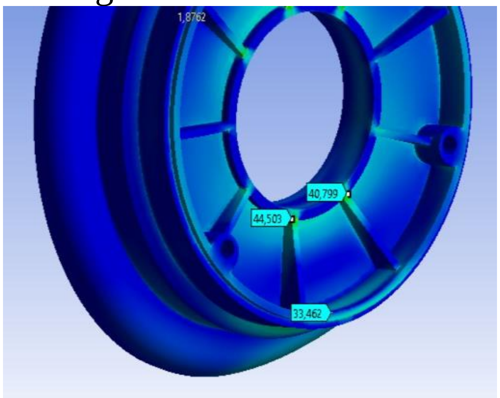


Figure 3 - Stress Distribution

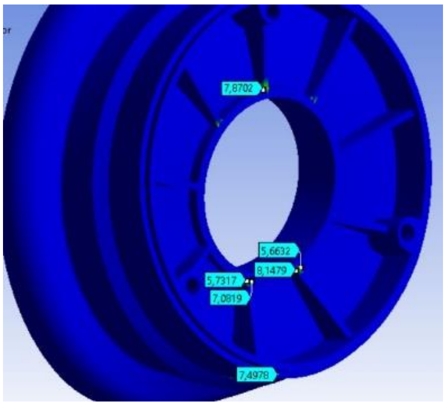


Figure 4 - Safety Factor Distribution

Conclusion.

1. Hard landings will cause instantaneous stress formation in the rim ribs. Therefore, the rib areas of the rims to be used in the landing gear should be carefully examined for possible cracks, especially after production or very hard landings.

2. In properly manufactured rims, the rib area stresses are not very high even in hard landings. Analogically, it has a high safety factor.

3. If the aircraft is used for training purposes, it will be used on very short runways, or a lighter rim material will be selected, the rib corners should be revised by filleting, and stress distribution should be provided in this way.

References:

1. N. ARAI, S. HARADA, and T. AIDA, "Research on the bending strength properties of thin-edged spur gears," *JSME Bull.*, vol. 24, no. 195, pp. 1642–1650, 1981.

2. S. ODA, K. MIYACHIKA, and K. ARAKI, "Effects of rim thickness on root stress and bending fatigue strength of internal gear teeth," *JSME Bull.*, vol. 27, no. 230, pp. 1759–1764, 1984.

3. S. ODA, K. MlYACHIKA, and T. SAYAMA, "Effects of rim and web thicknesses on bending fatigue strength of internal gear," *JSME Bull.*, vol. 29, no. 248, pp. 586–592, 1986.

4. A. A. Bol'shikh, D. S. Vdovin, and G. P. Eremin, "Calculation investigation of the strength of the composite wheel rim," *Izv. MGTU MAMI*, vol. 12, no. 1, p. 2—9, 2018.

5. N. F. Jabidi and R. Mahmudin, "Analysis of the Performance of Wheel Rim for Impact Test: Wheel Rim Impact," *Prog. Eng. Appl. Technol.*, vol. 2, no. 1, p. 842—854, 2021.

UDC 533.63,534.23

Dusheba O., Lukianov P.

CALCULATION OF BLADE NOISE IN ANSYS

Calculation of aerodynamic noise was performed using ANSYS software. For the angle of attack $\alpha = 5^{\circ}$ and flow velocity (M=0.475), rotation speed of 7000 rpm, a flow model around the profile was built. Fig.1 shows the flow pattern around the profile, where the numbers 1, 2, 3, 4 indicate the reference points for sound registration. The centre of the coordinate system is at the profile nose. Based on the results of the calculations, the graphs of the acoustic pressure dependence (Fig.2-Fig.3) were constructed for different reference points in the flow. These dependences indicate the presence of unsteady sound pulsations in the flow. Using the Fourier transform with a Hamming filter, the spectra of sound vibrations (SPL) were constructed (Fig.4-5). The calculated time was t=0.01s. According to the Courant-Friedrichs-Levy criterion, the time step was respectively $\Delta t = 5\times10^{-6}$s .

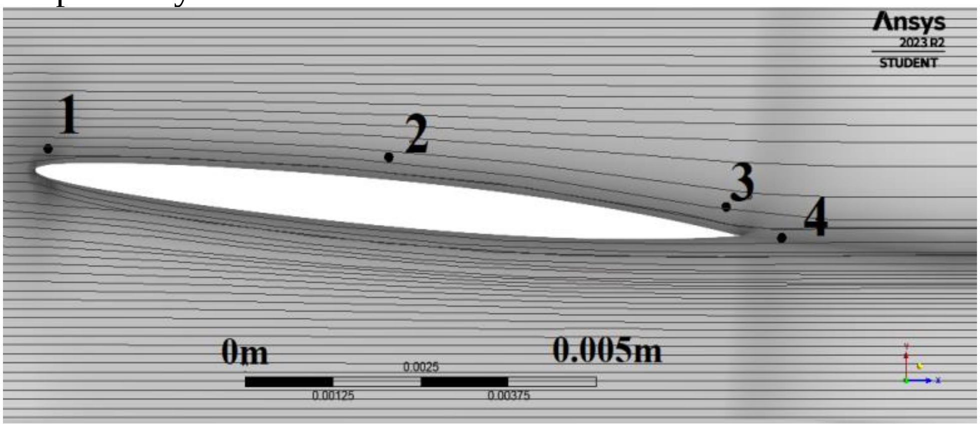


Figure 1 - Streamline of the profile and location of the sound study reference points for the 2d case

The graphs of sound pressure over time at reference points 1, 2, 3, 4 for the 2d case (Fig.1) obtained from the calculations are presented in Figs. 2-5. They show significant pulsations, which indicate the presence of a sound generation process, rotational noise, during the blade streamlining. Table 1 shows the coordinates of the sound recording points and the corresponding maximum pressure differences and maximum noise level in dB. The high value of the noise level, , in the immediate vicinity of the blade is realised because in the representation of the far sound field (6), the distance to the blade R is in the denominator. And this representation has a similar form in all models without exception, including those implemented in ANSYS.

To obtain the sound characteristics at more distant areas from the blade, as well as for more realistic modelling, a 3D model of the screw was created (Fig. 6), as well as a model of its rotation in the ANSYS package. The sound characteristics were calculated at five reference points, Fig.7. With an increase in the value of R, the noise level decreases significantly, and the sound wave turns into a homogeneous plane wave. At the same time, the pressure change is uniform, Fig. 8

Table 1. Calculated data at points 1,2,3,4 near the blade

Point No.	*X, mm*	*Y, mm*	*Max Pressure Δ, Pa*	*Max SPL*
1	0,20	0,33	1000	140
2	5,13	0,20	20	130
3	10,00	0,40	30	125
4	10,88	0,90	15	125

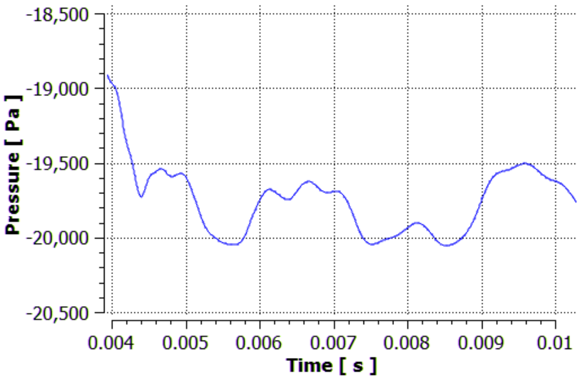


Figure 2 - Pressure distribution

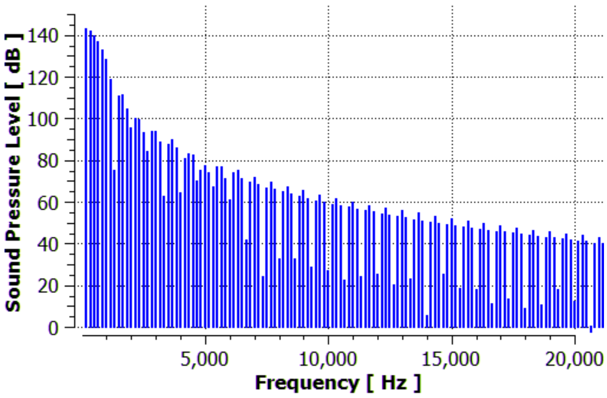


Figure 4 - Sound Pressure Level

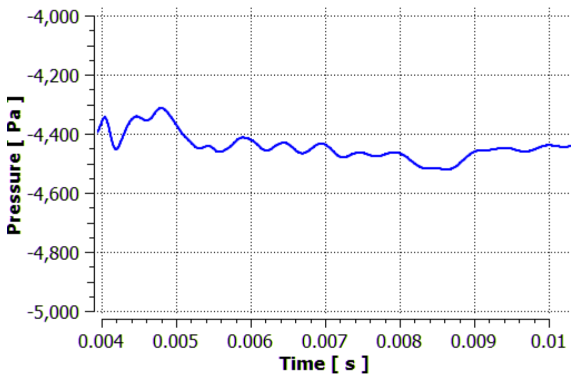


Figure 3 - Pressure distribution

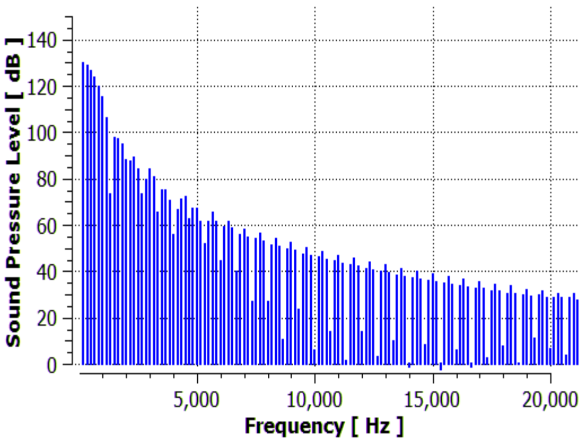


Figure 5 - Sound Pressure Level

As we can see, the level in the noise spectrum at point 1, Fig.4, reaches 80 dB at 233.3 Hz. Additional peaks in the spectrum are observed at frequencies of 466.6 Hz, 700 Hz, and 933.3 Hz. Thus, the rotation noise is dominated by the rotation frequency that has twice the propeller speed, i.e. the propeller speed multiplied by the number of blades. For all other points, however, these peaks are much less pronounced. In [1], the highest noise level was 78 dB, which closely coincides with the calculated data in Fig.5. As noted in the comparison above, similar values of the sound pressure level, about 80 dB, are also given in [1].

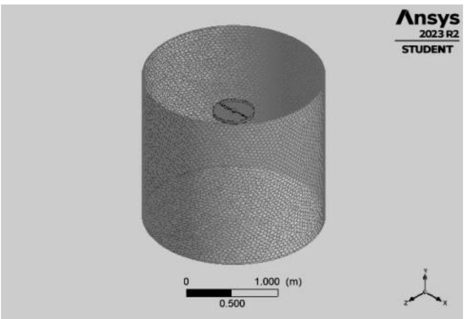


Figure 6 - Computational model of points. The grid spacing is 0.2 m the propeller

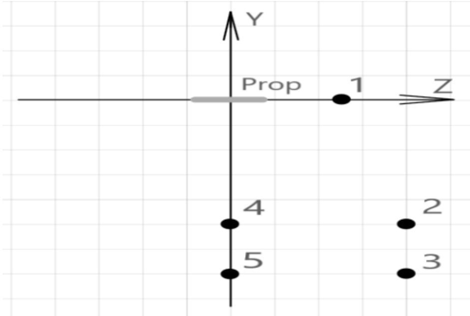


Figure 7 - Location of sound fixation

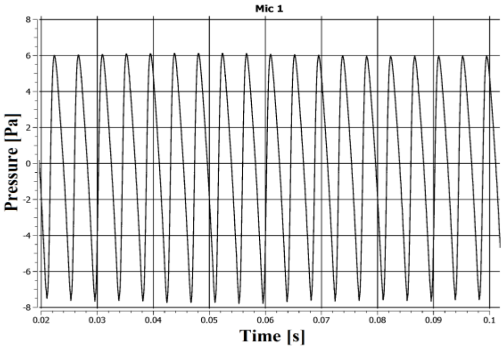


Figure 8 - Sound pressure distribution

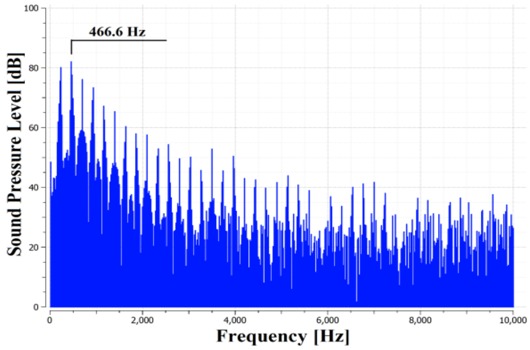


Figure 9 - Sound spectrum

It is worth to note that with distance from the propeller, the maximum sound pressure level at 233 Hz becomes less pronounced. In addition, with further distance from the blade, the sound source, the noise level at high frequencies decreases significantly, while at low frequencies it remains. This indicates that the far sound field has a predominantly low-frequency noise spectrum. The results obtained in ANSYS show that the main frequency content of the noise is contained in the first 6-7 harmonics and the energy of the sound, the rotational noise, is in the range of up to 2000 Hz.

Conclusions. Aerodynamic calculations and noise generation around the quadcopter blade using ANSYS software revealed that sound vibrations of up to 120 dB occur when the blade tip flows around the blade. Calculations using a 3d model of the propeller confirmed that the sound pressure level was already 80 dB at the nearest reference point. At a distance of about 5-6 blade lengths, the noise level drops to 60 dB, which is consistent with the results of other studies, as well as the studies in paragraphs 1-5 of this paper.

References:

1. Massey, K., Gaeta., R. Noise Measurements of Tactical UAVs. 16th AIAA/CEAS Aeroacoustics Conference. https://doi.org/10.2514/6.2010-3911

UDC 629.7

Dymarchuk Y., Marynoshenko O.

VIBRATION PROTECTION SYSTEM FOR UAVs

Introduction. The rapid expansion of unmanned aerial vehicles (UAVs) across industries such as logistics, environmental monitoring, and defense underscores their versatility and operational efficiency in diverse environments. This growing demand requires robust, adaptable UAV systems capable of performing complex tasks in challenging conditions. Hybrid and electric-powered UAVs, in particular, represent a key segment of this market due to their environmental benefits, improved energy efficiency, and suitability for sustained flight missions. Despite these advantages, hybrid and electric UAVs are prone to operational challenges, with vibration-induced issues being among the most critical. Vibrations from engine dynamics, rotor interactions, aerodynamic forces, and external disturbances can degrade UAV performance by reducing component lifespan, compromising flight stability, and impairing sensors and cameras. Addressing these issues is essential for maintaining UAV operational effectiveness and mission precision.

Statement of the Problem. Traditional approaches to UAV vibration control rely heavily on passive damping systems that, while effective in mitigating specific vibration types, lack the adaptability required to respond to rapidly changing operational conditions [1]. With UAVs increasingly deployed in variable and unpredictable environments, the limitations of passive systems become evident. Therefore, there is a clear need for an adaptive vibration protection system that can respond in real time to fluctuating conditions, adjusting its parameters to maintain stability and reliability. This study addresses this need by investigating the integration of intelligent materials and machine learning-based control algorithms, aimed at creating a responsive, efficient vibration protection solution for hybrid and electric UAVs [2]**.**

Statement of the Main Materials of the Study. The proposed research investigates an adaptive vibration protection solution specifically designed for hybrid and electric UAVs. By leveraging intelligent materials, such as piezoelectric and metamaterials, the system can dynamically adjust to variations in vibration frequencies and amplitudes. The study is structured into several key phases:

- Analysis of Vibration Sources in UAV Power Units and Airframes: This phase involves a detailed examination of the primary vibration sources that impact UAV stability and component wear, particularly for hybrid and electric systems. High-frequency vibrations from electric motors and hybrid engines require specialized damping solutions that differ from those used in conventional fuel-powered UAVs. This analysis will provide a foundation for selecting the most effective vibration mitigation approaches.
- Intelligent Material Selection and Application: The use of advanced materials capable of altering their properties in response to environmental stimuli represents a promising avenue for adaptive vibration control. Piezoelectric materials, which can convert mechanical stress into electrical energy, and metamaterials, with

their unique physical structures, will be evaluated for their ability to attenuate vibrations. These materials can be strategically integrated into UAV structures to provide localized damping that adjusts to varying operational conditions.

- Adaptive Control System Design Using Machine Learning: An essential component of the proposed system is the adaptive control mechanism based on machine learning. Sensor data collected during flight will feed into algorithms that can adjust damping characteristics in real-time, optimizing the system's response to different types of vibration. Techniques such as reinforcement learning and adaptive filtering will be employed to fine-tune the response patterns. This intelligent control mechanism enables the system to actively reduce vibration impact across a wide frequency range, thus enhancing overall UAV stability and reliability.
- Prototyping and Experimental Validation: A UAV prototype equipped with the adaptive vibration protection system will be developed to test the effectiveness of the proposed approach. Laboratory tests will simulate a range of vibration scenarios, while field tests will assess performance under real-world conditions. Key metrics for evaluation will include vibration reduction efficiency, component durability, and improvements in flight stability and sensor accuracy.

Conclusions. The proposed adaptive vibration protection system represents a significant advancement in UAV design by combining the responsive capabilities of intelligent materials with machine learning-based control. This approach offers a robust alternative to traditional passive damping methods, enabling real-time adaptability and enhanced resilience for hybrid and electric UAVs. The system's ability to mitigate vibration impacts will lead to improvements in UAV reliability, reduced maintenance costs, and longer operational lifespans. These outcomes have the potential to address the growing demand for high-performance UAVs in various industrial sectors, supporting their deployment in applications that require stability, accuracy, and durability under diverse environmental conditions.

References:

1. De Silva, C.W. (Ed.). (2007). Vibration Damping, Control, and Design (1st ed.). CRC Press. https://doi.org/10.1201/9781420053227
2. Korobiichuk, I.; Mel'nick, V.; Kosova, V.; Pavlenko, V.; Bursacov, K. Study of Systems of Active Vibration Protection of Navigation Instrument Equipment. Appl. Syst. Innov. 2024, 7, 95. https://doi.org/10.3390/asi7050095

UDC 629.7

Ibrahimoglu B., Kabanyachyi V.

DEVELOPMENT OF PRIORITY SCHEME FOR MOTION CUEING ALONG SEVERAL DEGREES OF FREEDOM

Statement of the Problem. Flight simulator is the main technical means for pilot training and retraining. And while piloting on simulator is differ from piloting on airplane, using simulators instead of airplanes has significant advantages. Such large companies as CAE Electronics and Thales Training & Simulation, as well as individual aviation enterprises, in particular JSC "Antonov", are engaged in development of simulators. The growth rate of flight simulator fleet of higher qualification levels exceeds the growth rate of aircraft fleet. In Ukraine there is a need to develop flight simulators for aircraft under development and to modernize existing flight simulator fleet that would meet modern requirements.

Many investigations [1 - 5] of motion cueing were conducted in order to increase motion cueing fidelity. Motion cueing as in real flight is possible only with accurate reproduction of aircraft spatial motion. Due to limited constructive resources of flight simulators in comparison with aircraft resources, it is impossible to continuously monitor an aircraft's movement. On the other hand, only motion perception is important for pilots. Therefore, during motion cueing, it is important to consider not only motion system movement itself but also created motion cues and how accurately their perception on flight simulator corresponds to real movements resulting from same control actions.

The subject of this work is research a scheme for motion cueing simultaneously along several degrees of freedom on flight simulator. The proposed scheme takes into account peculiarities of occurrence, simulation and perception of aircraft spatial movement. Research method is based on Gibson's perception theory, according to which perception of motion cues occurs according to characteristic features such as time of appearance, direction, intensity and duration of perception of motion cues. It is also taken into account that although pilot perceives movement along several degrees of freedom simultaneously, he can be piloting along one degree of freedom only.

Statement of the main materials.

Developing a highly efficient simulating method of motion cues of non-maneuvering aircraft along several degrees of freedom, which provides spatial simulation of motion cues consistent with real ones along all six degrees of freedom includes two components:

taking into account peculiarities of occurrence and simulation of motion cues caused by aircraft spatial movement;

taking into account structural resources of motion system.

Conducted studies have shown that a person has only one decision-making channel, through which all information gradually passes, and that in the process of multi-channel control, a person works as a single-channel regulator with sequential switching of attention. This factor, as well as the presence of minimum time intervals between the appearances of perceived motion cues, are the backgrounds for using the priority scheme for the motion cueing along degrees of freedom: motion cues along linear degrees of freedom are considered independent of each other, and the motion cueing is carried out in this way.

In order to achieve the set goal and solve the formulated problem, it was solved the following tasks:

- Considering the special importance for piloting the aircraft movement along pitch, its simulation has an absolute priority and is carried out under any conditions.
- Together with motion cue along longitudinal degree of freedom, only the aircraft pitch movement and motion cues along yaw are simulated.
- Together with motion cues along the vertical degree of freedom, only the aircraft pitch movement and motion cues along roll are simulated.
- Together with motion cue along lateral degree of freedom only the aircraft pitch movement and motion cues along roll and yaw are simulated.

Conclusion. The research results show that the most important is motion cueing along linear degrees of freedom, and motion cueing along angular degrees of freedom essentially depends on the aircraft flight mode. It is possible to simulate motion cues on flight simulator close to real motion cues along longitudinal, lateral, vertical degrees of freedom, roll and yaw, and to simulate the aircraft movement along pitch using motion system with 1.5 m jacks.

References:

1. Preliminary assessment of influence of flight simulator mobility on the piloting process and analysis of compartment motion control methods: Report of the Research Institute/ TsAGI, No. GR 015110-1, inv. No. 655. - M. - 1970. - 34 p.
2. Aleksandrov V.V., Sadovnichy V.A., Chugunov O.D. Mathematical problems of dynamic flight simulation. - M.: Moscow State University. - 1986. – 181 p.
3. Bussolari S.R., Young L.R., Lee A.T. The Use of Vestibular Models for Design and Evaluation of Flight Simulator Motion // Collect. Techn. Pap. "AIAA Flight Simul. Technol. Conf. and Exhib.", Boston, Aug. 14-16, 1989. – Washington (D.C.). – 1989. – p. 86-93.
4. Hall, J.R. The Need for Platform Motion in Modern Piloted Flight Training Simulators, Tech Memo FM 35, Royal Aerospace Establishment, Bedford, UK, October 1989. – 16 p.
5. Volodymyr Kabanyachyi, Beycan Ibrahimoglu Consideration of the problem of motion cueing along angular degrees of freedom on flight simulators// Technological Audit and Production Reserves, No. 6, 2023, pp. 6–12. DOI: 10.15587/2706-5448.2023.293498

UDC 629.7

Karmazin S., Bondarenko O.

STRUCTURAL MODELS FOR DETERMINING THE RESOURCE OF ELEMENTS OF AIRCRAFT MADE OF COMPOSITE MATERIALS

Introduction. Due to excellent properties and the permanent improvement of composite materials, the volume of their application in aviation technology is continuously increasing. Recently, the amount of such elements used in the modern aircraft design has reached the level of 30-50%. Likely, the number will grow in future.

Today, composites are widely applied in the primary aircraft structure. They perform under higher and more intense loads, levels of vibration and severe operating conditions, which makes them susceptible to defects as cracks, voids and irregularity [1]. Therefore, solving the problem of predicting the resource of aircraft elements made of composites is becoming an important scientific task.

Scientific and technical results. There are three general tasks (phases) in the determination of the resource:

1) Calculating the moment when a defect occurs and starts growing;
2) Estimating the time range and potential directions of propagating a defect in an element – residual life;
3) Predicting the time when a defect reaches critical dimensions – the boundary state.

The goal of this scientific research is to develop structural models allowing calculating and forecasting the three above phases with the usage of apparatus of probability theory, Markov process and the conventional statistic distribution likely Weibull. For example, the equation for the conditional reliability function $P(t \mid T_k)$ in the general case of an n-dimensional diffusive Markov process in a stationary system allows to calculate the residual life and has the form [2]:

$$\frac{\partial P}{\partial t} = \sum_{j=1}^{n} \varkappa_j(\boldsymbol{V}_k)\frac{\partial P}{\partial v_{jk}} + \frac{1}{2}\sum_{j=1}^{n}\sum_{l=1}^{n} \varkappa_{jl}(\boldsymbol{V}_k)\frac{\partial^2 P}{\partial v_{jk}\partial v_{lk}} \tag{1}$$

where v_{jk} - components of vector $\boldsymbol{V}_k \equiv \boldsymbol{V}(t_k)$;

$\boldsymbol{V}_k$ - a vector characterizing a process;

$\varkappa_j$, $\varkappa_{jl}$ - process intensity coefficients.

The representation of composite elements at the structural level of “matrix”, “fiber” and “fiber – matrix” is a promising direction for predicting their resource and service life. The strength of the matrix, the fiber and the “fiber – matrix” interface (analogically to the theory of adhesive bonds) are required to be explored. Markov process is supposed to be used for modeling the process of growth of micro- and evolution of them into macro-cracks (Fig. 1). The statistic distribution will help to determine time T_*, which is a moment when the initial crack reaches its critical length L_*. When a structural element reaches a limit state at $L_{crack} = L_*$, a decision can be made regarding its serviceability, the possibility of further safe operation, or the need to replace or repair it [3].

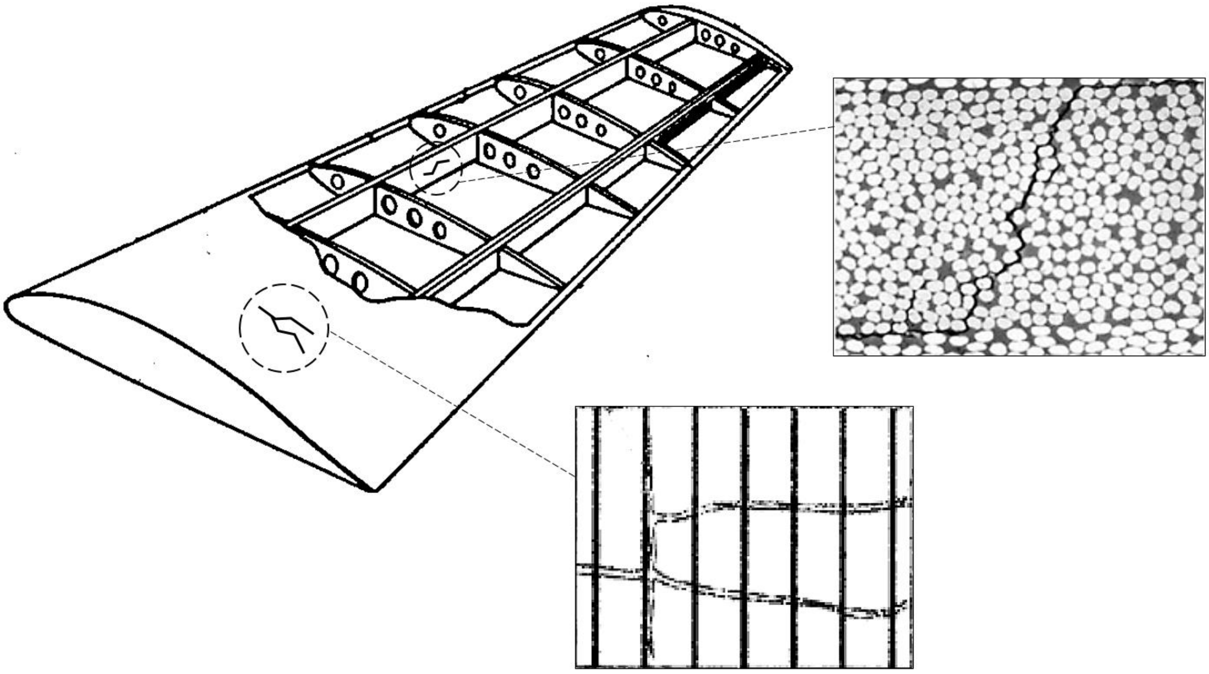


Figure 1 – Examples of crack propagation in composite elements of wing structure

The accuracy of the modeling results to the values obtained from the experiment by one order of magnitude will be considered a criterion for the successful implementation of structural models.

It is assumed that the structural models will allow to conduct less experiments to prove their accuracy and effectiveness. Determination of strength characteristics of a composite material becomes less important in this case. The main difficulty here is to establish relationships between fiber and matrix as closer as possible to the real objects.

Conclusion. Summarizing the above discussion, structural models are considered as a promising way of development of new methods for predicting the resource of elements made of composites.

It is expected that structural models will provide more precise results and less dispersion of values than it would be in case of the usage of other types of models, the accuracy of which significantly depends on the quantity of conducted experiments, that can be very expensive.

References:

1. Mehdikhani, M., Gorbatikh, L., Verpoest, I. & Lomov, S. V. (2018b). Voids in fiber-reinforced polymer composites: A review on their formation, characteristics, and effects on mechanical performance. Journal of Composite Materials, 53 (12), 1579–1669. doi:10.1177/0021998318772152.

2. Bogachev, V., Krylov, N., Röckner, M. & Shaposhnikov, S. (2015). Fokker–Planck–Kolmogorov equations. Mathematical surveys. doi:10.1090/surv/207.

3. Tran, T. N. D. & Piat, R. (2024b). Numerical studies of crack propagation in composites reinforced by irregular particles. Procedia Structural Integrity, 52, 366–375. doi:10.1016/j.prostr.2023.12.036.

UDC 629.735.5

Klymenko A., Gryshanova I.

COMPARATIVE ANALYSIS OF EVTOL AIRCRAFT CONFIGURATIONS

Introduction. The idea of a small aircraft operating in urban environments, a “flying car” of sorts, can be traced back to at least the 1950s, and has gained recognition in popular culture. However, only in recent years the development of such vehicles has shown significant progress, thanks to the advancements in aerodynamics, flight control, composites and propulsion technology.

Current versions of the concept mostly use electric propulsion, and thus can be described as electric vertical take-off and landing aircraft (*eVTOLs*). They are usually powered from batteries, but the term also includes hybrid vehicles with hydrogen fuel cells or conventional engines providing power to electric motors.

Such aircraft may be used as “air taxis” for on-demand urban and short-distance regional flights, as personal transport, for cargo delivery, medical evacuation and other roles. Many technical, economic and environmental factors contribute to the choice of electric powerplants, including mechanical simplicity and reliability, power distribution, low operatinal costs, noise and emissions.

Analysts predict that eVTOLs will have a big market share in the near future, but they also face serious challenges. One of the main technical limitations is the low energy density of lithium-ion batteries, which limits range and demands high efficiency. Their proposed model of operations also creates legal and regulatory challenges and requires very high reliability.

Main materials of the study. The aim of this study was to provide a comparative analysis of various eVTOL configurations in development. 8 projects that have reached advanced development phases were chosen as examples of major eVTOL layouts. In the development and analysis of aircraft configurations, CFD software is widely used to determine their aerodynamic performance, acoustic environment, stability, energy efficiency and other characteristics.

In their design, eVTOLs are very distinct from traditional aircraft and differ from each other. Their main feature is using multiple electric propulsors, up to 36 units on a single aircraft. Tilting rotors, engine pods or wings are often used for transitioning between vertical and horizontal flight. Propulsion is provided by conventional propellers or ducted fans.

EVTOLs’ complicated powerplants and varying flight modes require a highly automated control system to keep the aircraft stable in vertical, transition and horizontal flight. Such advanced systems allow for a mostly automatic flight to a specified destination, blending the line between crewed aircraft and UAVs. This further allows for cargo UAVs to be developed from passenger vehicles.

Four general configurations are described, based on propulsion system layout: multicopters with vertical lift rotors only; lift-cruise configuration with separate propulsors for vertical & horizontal flight; vectored thrust, such as tiltwing or tiltrotor, with the same propulsors used for cruise and vertical flight; and hybrid layouts using both vectored and vertical lift-only propulsors. Wing configurations also vary, with the most popular being tandem wing, canard or conventional V-tailed layout. Airframes are largely made of composite materials.

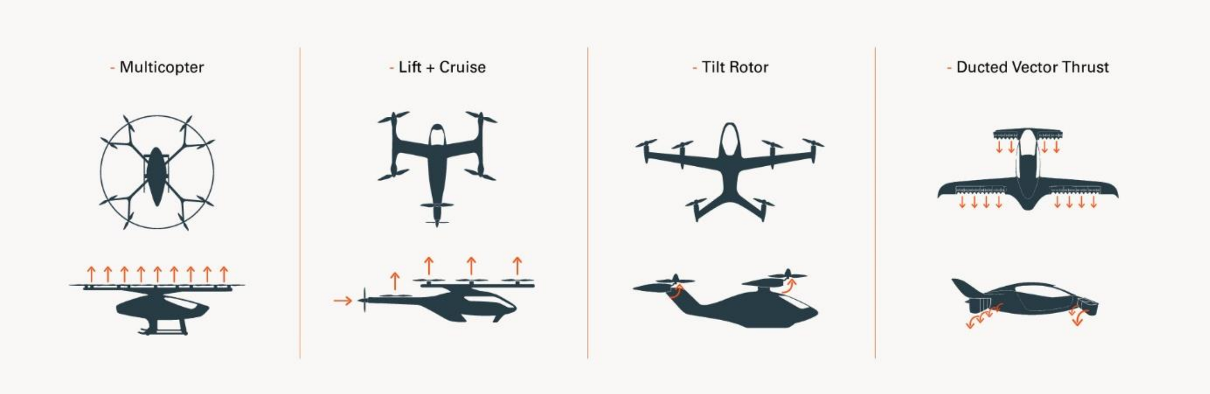


Figure 1 - Major eVTOL propulsion layouts

Of the example vehicles studied, designs by Volocopter and EHang are multicopters, Autoflight Prosperity and Beta Technologies ALIA-250 use lift-cruise layout, Joby S4 and Lilium Jet have vectored thrust (tiltrotor and vectored ducted fans), while Archer Midnight & XTI TriFan 600 use hybrid designs.

All designs have their pros and cons: multicopters are only suitable for short range flights; vectored thrust systems are more mechanically complex, and propulsor performance may be suboptimal for one or both phases of flight; lift-cruise allows to separately optimize VTOL and cruise propulsors, but they are dead weight during the other flight phase; hybrid solutions take some advantages and downsides from both lift-cruise and vectored thrust layouts.

Conclusions. This study identifies key features of eVTOL aircraft currently under development, their possible uses, prospects and major risks of their development. Main technical features were selected, possible aircraft layouts were analyzed for their advantages and drawbacks.

References:

1. Higgins R.J., Barakos G.N., Shahpar S., Tristanto I. A Computational Fluid Dynamic Acoustic Investigation of a Tiltwing eVTOL Concept Aircraft. Aerospace Science & Technology, 2021, vol. 111.

2. Johnson W., Lau B.H., Bowles J. Calculated Performance, Stability and Maneuverability of High-Speed Tilting-Prop-Rotor Aircraft. NASA-TM-88345, Ames Research Center, Moffett Field, California, September 1986.

3. Su J., Huang H., Zhang H., Wang Y. and Wang F.-Y. eVTOL Performance Analysis: A Review From Control Perspectives. IEEE Transactions on Intelligent Vehicles, May 2024, vol. 9, no. 5, pp. 4877-4889

4. Laskowitz I.B. Vertical Take-off and Landing (VTOL) Aircraft. Annals of the New York Academy of Sciences, 1963, vol. 107, art. 1, pp. 163-186.

UDC 629.7.022

Kovalenko O., Korobko I.

EVALUATION OF AERODYNAMIC CONFIGURATIONS IN MODERN WIG DESIGNS INTRODUCTION.

Introduction. In recent years, attention to environmental protection has been growing, which stimulates the development of effective resource-saving systems. This prompted scientists to intensify the development of Ground-effect vehicle (WIG). Such aircraft use the effect of proximity to the surface of the earth or water on the aerodynamic characteristics of the wing, which significantly increases its load-bearing capacity and reduces drag, allowing it to fly longer distances and save fuel.

At the beginning of their development, WIGs were large low-speed vehicles for transporting cargo. Since none of the concepts have ever gone into mass production, and research in this area has been significantly reduced, this topic remains understudied. The main problem is the development of an optimal aerodynamic layout that takes into account the specific operating conditions in proximity to the surface of the earth or water.

Scientific and technical results. Analyzing the development of aircraft, the operation of which is based on the screen effect, we can distinguish three main schemes of WIG: Tandem configuration, Airplane-type wing-tail configuration, Flying wing configuration [1]. The tandem circuit provides static stability and effective control, but only works within the ground effect. To date, this scheme has not been widely used. Aircraft with the airplane-type wing-tail configuration have a large altitude range, can avoid obstacles, and are more maneuverable. The disadvantages of this scheme are the rather large weight of the tail and the relatively small value of the lifting force. A modified version of the previous configuration is the Lipisch scheme, which has good maneuverability, a high lift coefficient, a large range of operating heights and pitch angles, and the ability to perform a "dynamic jump". The main idea of the flying wing scheme is to transform the entire aircraft body into a surface that creates lift. From an aerodynamic point of view, this scheme is quite effective, as it allows reducing drag, but it is difficult to ensure stability, controllability, and seaworthiness.

In addition to the three main schemes considered, there are designs and studies of other configurations. The paper “Analysis of drag and lift forces in different tailed ground effect vehicles” [2] presents the results of studies of WIG with different tails, the analysis of which outlines that the best ratio of lift to drag coefficients has a V-tail.

Experimental studies in a wind tunnel of a WIG model with a combined wing showed that the proposed tips increased the lift coefficient [3].

In [4], an aircraft design methodology is presented, according to which an unmanned ground effect vehicle (UGEV) was developed. The design of the model combined the basic geometry characteristics of the blended wing body (BWB), and box wing (BXW) configurations. This hybrid layout, which combines the best characteristics of both configurations, allows the aircraft to cope with adverse flight conditions within the atmospheric layer. An interesting feature of this work is the study of flow control methods. The authors focused on such things as wing fences, tubercles, as well as the morphing concept. Research results have shown that both tubercles and wing fences increase aerodynamic efficiency, that is, they can help increase the weight of the payload. As for the morphing technologies evaluation studies, only two are optimal for UGEV. The first involves lowering the ends of the wing towards the water during landing, but it causes great limitations to the concept. The second option provides for a flexible lower casing, this option was used as a result. The authors believe that the research results are quite encouraging and that this concept should be developed further.

A more complex and unusual concept of UGEV is proposed in [5]. This model has a wing that consists of three parts. This is done so that the wing folds.

There are known modern WIGs that are only at the design stage or have already been built: ARON M80, Liberty Lifter, Flying Ship, have airplane-type configuration.

Conclusion. The reviewed publications demonstrate that there is currently no optimal configuration that would be followed by the majority of designers. A review of recent developments allows us to conclude that aircraft-type designs have become the most widespread among modern WIG projects. Future research will focus on testing the main WIG configurations, comparing their aerodynamic characteristics and identifying trends in the development of this class of modern aircraft.

References:

1. Yun L., Bliault A., Doo J. (2010), WIG Craft and Ekranoplan. Boston, MA : Springer US. (date of access: 13.06.2024). URL: https://doi.org/10.1007/978-1-4419-0042-5

2. Pavan Hiremath, Manjunath Shettar, Suhas Kowshik C. S. та Rajath J. and Sukhesh P. D., (2019). Analysis of drag and lift forces in different tailed ground effect vehicles. *International Journal of Mechanical Engineering and Technology (IJMET)*. 10(1), 1399–1412.

3. Tofa, M. M., Maimun, A., Ahmed, Y. M., Jamei, S., Priyanto, A. та Rahimuddin, (2014). Experimental investigation of a wing-in-ground effect craft. The Scientific World Journal. 2014, 1–7. [date of access: 13.06.2024]. URL:: doi: 10.1155/2014/489308

4. Papadopoulos C., Mitridis D., Yakinthos K., (2022), Conceptual Design of a Novel Unmanned Ground Effect Vehicle (UGEV) and Flow Control Integration Study. *Drones*.. 6(1), 25. (date of access: 13.06.2024). URL: https://doi.org/10.3390/drones6010025.

5. Shuang X., Zhang Y., (2021) Design of Unmanned Wing-in-ground Effect Vehicle with Tri-fold Main Wing. *E3S Web of Conferences*., 248, 02062. (date of access: 13.06.2024) URL: https://doi.org/10.1051/e3sconf/202124802062.

6. Surjatin Wiriadidjaja, Zahratu Hillal binti Mohamad, Azmin Shakrine Mohd Rafie. Wing-In-Ground-Effect Craft as a Potential Domestic Transport Vehicle. *American Institute of Aeronautics and Astronautics*. 2016. URL: https://doi.org/10.2514/6.2016-3879.

7. Li R., Chen H. (2017), The Feasibility of High Speed Ground Effect Vehicles. *17th AIAA Aviation Technology, Integration, and Operations Conference*, Denver, Colorado. Reston, Virginia. (date of access: 13.06.2024). URL: https://doi.org/10.2514/6.2017-3423.

UDC 629.7

Kuzminova M., Arkhypov O.

COMPOSITE ROCKET FIN

Statement of the problem. For the longest time aerospace industry has been dominated by metals and their alloys as the main structural material. However, since the invention of the composite structures in 1950s they have been gradually replaced in this and many other industries, and there are several reasons for that [1]. One of them is significant weight reduction as composite materials are usually 3-5 times less dense than their metal counterparts. Another reason is that composites can be designed to provide great mechanical properties specifically required for a particular project. Fiber-reinforced polymers are among the most popular composites in our industry, carbon prepregs being in the lead.

Unlike metals and their alloys, which are supplied as a prepared product, composite materials need to be designed.

Fabrication technique of a composite structure selection is crucial and takes place during the design phase. Fabrication technique directly influences cost and speed of manufacturing, precision of the surface and fiber volume fraction in the product [2].

Statement of the main materials of the study. In this study an attempt to design a composite rocket fin panel was made. A loaded panel with dimensions of 1400*360mm was considered.

Comparative calculations for two carbon fiber reinforced polymers KMU-3 and KMU-4E and one boron fiber reinforced polymer KMB-3M were carried out. Two versions of the structure were designed a solid panel and a sandwich structure.

Number of layers was estimated for the given stress, including general number of layers and directional layers of 0˚, 90˚ and ±45˚. Their layout was determined. Mechanical characteristics of the structures were calculated. Tsai-Hill failure criterion was used for evaluation.

Honeycomb core thickness was determined for sandwich panels and a fiberglass material AMg2N was chosen for this purpose.

The structures were then evaluated based on their mass, as mass reduction is one of the main reasons to implement composite materials. The best results, meaning the lowest mass, was gained for KMU-3, coming up to 1,59kg for the solid panel and 2,79kg for sandwich panel.

Despite the fact that boron fibers usually have better mechanical characteristics, based on the results of mass calculations, KMU-3 was chosen as the optimal fiber for this project.

General number of layers for both solid and sandwich KMU-3 panels came up to 14, with number of layers in 0˚ direction being 4, in 90˚ direction – 4, and in ±45˚ direction – 6. The layout for the solid panel is as follows:

0, +45, 90, -45, 0, +45, 90 | 90, +45, 0, -45, 90, +45, 0

for the sandwich panel:

0, +45, 90, -45, 0, +45, 90 honeycomb 90, +45, 0, -45, 90, +45, 0.

The thickness of the laminate came up to 2,1mm. The honeycomb core thickness was calculated to be 33mm.

To increase the fracture toughness, a hybrid composite was developed [3] by adding a layer of glass fiber under two layers of carbon fiber with an orientation of 0˚. As the calculation proved, this had almost no effect on the mechanical characteristics of the structure.

As a fabrication method autoclave molding [4] was chosen. The assembly is vacuum bagged to get rid of entrapped air and then put in an autoclave where heat and pressure are applied at specific time intervals to cure the matrix. Though this method is costly and time consuming, it provides quality parts with high fiber volume fraction, great precision and low void content, as these qualities are crucial in aerospace industry.

Conclusions. As a result of this study a rocket fin panel was designed, a carbon fiber reinforced polymer KMU-3 was selected for it based on mass calculations. It was then turned into a hybrid structure with a goal to increase fracture toughness. Configuration of layers and laminate thickness was determined. Autoclave molding was selected as a fabrication method.

References:

1. Setlak L, Kowalik R, Lusiak T. Practical Use of Composite Materials Used in Military Aircraft. Materials, 2021. 14 no.17

2. Al-Furjan, M.S.H., Shan, L., Shen, X., M.S. Zarei, M.H. Hajmohammad, R. Kolahchi. A review on fabrication techniques and tensile properties of glass, carbon, and Kevlar fiber reinforced rolymer composites. Journal of Materials Research and Technology, 2022, vol 19, pp 2930-2959.

3. Ngatiman, Norazazi & Jumaidin, Ridhwan & Ab Ghani, Ahmad Fuad & Munir, Fudhail & Dhar Malingam, Sivakumar. Hybrid Carbon/Glass Fiber Reinforced Polymer; A Frontier Material for Aerospace Industry: A Review on Mechanical Properties Enhancement. Current Science and Technology, 2021, vol. 1, pp 41-51.

4. Akovali, G. Handbook of Composite Fabrication. Rapra Technology Limited. Ankara, 2001. p 84-87.

UDC 629.7.017.1

Kuznietsova M., Bobkov Y.

CARGO MULTICOPTER LANDING CONTROL SYSTEM USING FUZZY LOGIC

Introduction. Solving the problem of a safe and precise landing of a cargo multicopter is crucial and highly relevant. The weight of the cargo and the impact of external disturbances that cause displacement of the multicopter significantly affect landing accuracy. To determine the landing location and improve accuracy, it is advisable to use a technical vision system (TVS) and recognition algorithms. In this work, a landing control system for cargo multicopters was developed, utilizing TVS and fuzzy logic to consider these factors.

Scientific and technical results. An analysis of existing studies showed that multicopter landing control can use satellite navigation systems (GPS) [1], technical vision system [2], LIDAR (Light Identification, Detection and Ranging) [3]. A common drawback of existing studies is the lack of a comprehensive solution for locating the landing site, moving towards it, and descending with control of height, displacement, and speed, as well as considering the payload weight. In this study, TVS was chosen for addressing this problem. Since influencing factors are variable, especially displacement due to external disturbances, the use of fuzzy logic is proposed [4, 5, 6].

Multicopter Structural Diagram. The developed control system structure for the multicopter consists of interconnected blocks that ensure a reliable landing. Key components include a microcontroller-based flight controller, GPS module, radio communication module, motor controller block, actuators (motors), TVS, inertial navigation system (INS), barometric altimeter, gyrostabilized optical-electronic system, laser altimeter, image processing block, pre-processing information block, weight input block, and fuzzy logic block.

The TVS provides target identification and monitors multicopter displacement relative to its center. The barometric and laser altimeters control altitude at different landing stages. The current speed of the multicopter is determined by the flight controller data. (Figure 1).

Overview of the Fuzzy Logic Control System. The use of fuzzy logic provides a reliable method for dealing with uncertainty by mimicking human reasoning and decision-making. In this study, the fuzzy logic block (FLB) is responsible for processing and integrating data from various sensors, such as the TVS, INS, and weight input block, to make decisions on multicopter landing. The input variables for the fuzzy logic system are payload weight, multicopter displacement relative to the landing target center, and current height. The output is the descent speed of the multicopter during landing.

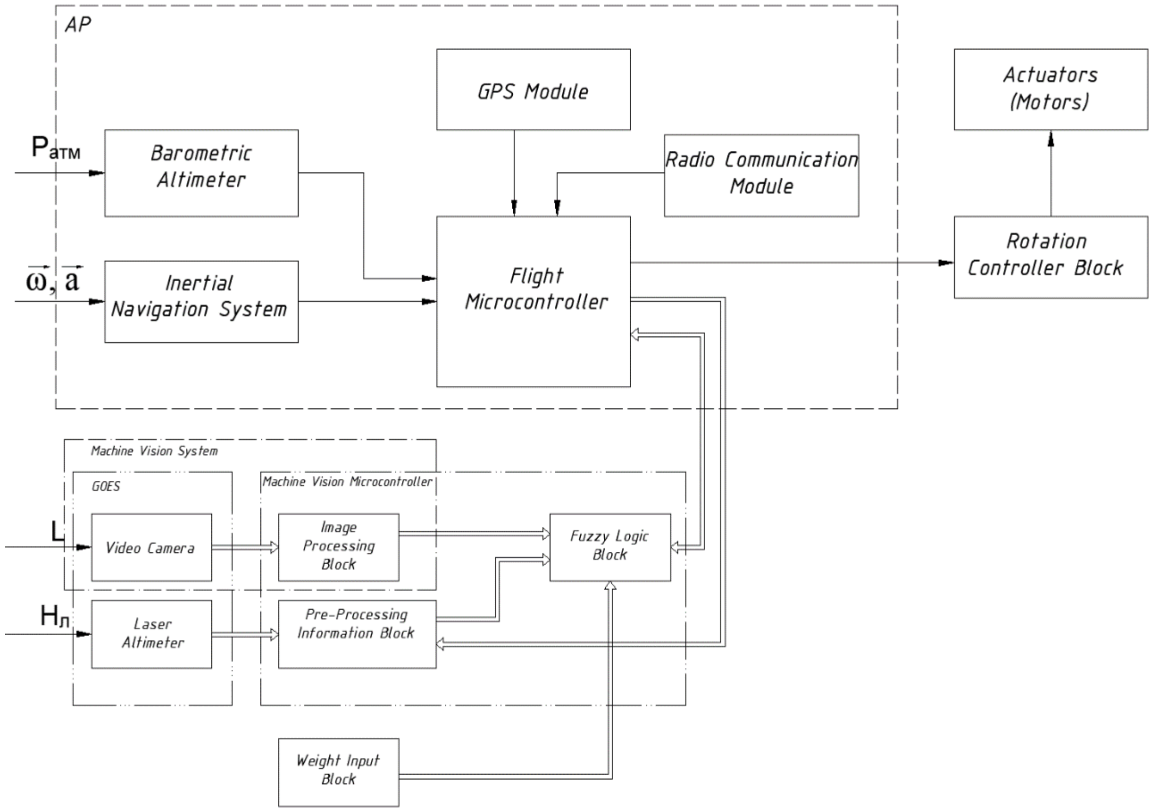
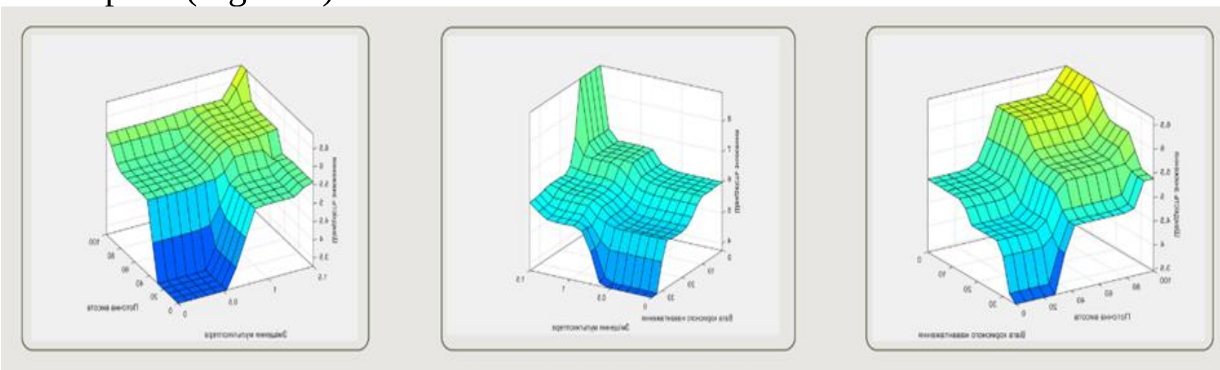


Figure 1 - Multicopter Structural Diagram

Fuzzification. Each input variable is divided into linguistic terms: height - low, medium, high; payload weight - light, medium, heavy; and displacement - small, medium, large. The descent speed is also divided into linguistic terms: low, medium, high.

Rule Base. Control logic is implemented through a rule base. For example, if the height is low, displacement is small, and payload weight is heavy, then the descent speed is low. This is realized using a Mamdani inference style[5] with max-min aggregation. The FLB uses 42 rules, which is sufficient for smooth landing control.

Defuzzification. The Centroid of Area (CoA) method was identified as the most optimal for this system, transforming linguistic results into precise numerical values of descent speed (Figure 2).



a) b) c)

Figure 2 - Control surface for:

a) Current height, payload weight, and descent speed;

b) Payload weight, multicopter displacement, and descent speed;

c) Current height, multicopter displacement, and descent speed.

Conclusion. he use of fuzzy logic for controlling the landing of a cargo multicopter provides significant improvements in safety by enhancing accuracy and adaptability.

The conducted simulations showed that the proposed landing control system provides smooth descent and precise landing with minimal horizontal displacement. This method outperforms traditional ones, making it a viable solution for future autonomous cargo delivery operations.

References:

1. A. Priambodo, F. Arifin, A. Nasuha, M. Muslikhin, i A. Winursito, "A Vision and GPS Based System for Autonomous Precision Vertical Landing of UAV Quadcopter", Journal of Physics: Conference Series, tom. 2406, p. 012004, December 2022, doi: 10.1088/1742-6596/2406/1/012004.

2. B. Lee, V. Saj, M. Benedict, i D. Kalathil, "A Vision-Based Control Method for Autonomous Landing of Vertical Flight Aircraft On a Moving Platform Without Using GPS", 16, Серпень 2020, arXiv: arXiv:2008.05699. Date of application: 25, December 2023. [Online]. Available in: http://arxiv.org/abs/2008.05699

3. F. Liu, J. Shan, B. Xiong, i Z. Fang, "A Real-Time and Multi-Sensor-Based Landing Area Recognition System for UAVs", *Drones*, tom 6, tom. 5, p 118, May 2022, doi: 10.3390/drones6050118.

4. O. Cetin, S. Kurnaz, i O. Kaynak, "Fuzzy Logic Based Approach to Design of Autonomous Landing System for Unmanned Aerial Vehicles", *Journal of Intelligent and Robotic Systems*, tom. 61, pp. 239–250, Berlin 2011, doi: 10.1007/s10846-010-9508-6.

5. M. Irfan, C. N. Alam, i D. Tresna, "Implementation of Fuzzy Mamdani Logic Method for Student Drop Out Status Analytics", *J. Phys.: Conf. Ser.*, tom. 1363, tom. 1, p. 012056, Nov/ 2019, doi: 10.1088/1742-6596/1363/1/012056.

6. V. S. Blintsov, L. T. Aloba, A. V. Nadtochii, V. A. Nadtochii, "Fundamentals of automatic control of a group of autonomous unmanned underwater vehicles", Mikolaiv, Ilion, 2022

UDC 629.7

Lisitsyn O., Bondar Y.

SCIENTIFIC BASIS FOR APPLYING ARTIFICIAL INTELLIGENCE IN DETERMINING THE SERVICE LIFE OF STRUCTURAL ELEMENTS IN TRANSPORT CATEGORY AIRCRAFT

Introduction. In the context of the trend towards maximum economic efficiency of using transport category aircraft, and active development of their "post-market" operation, determining and extending the service life of units, assemblies, and individual parts is relevant.

The service life of parts is being extended both by assigning new inspection intervals by the forecasting of crack initiation and propagation in an existing part with damage (corrosion, defects after repairs), and by complete replacement of the part with an identical one in geometry but made of a different material. In conditions of uncertainty of material properties for fatigue strength and parameters of crack initiation and growth (Wohler's curves [5], Stress Intensity factor, Crack growth rate diagram [1], parameters of Walker, Paris, NASGRO equations [5]), such forecasting is often made with significant assumptions (mainly based on "closeness of static allowables"), which entails substantial discrepancies with the actual properties of materials and gives both an overestimated and an underestimated values of the repair intervals in flight cycles.

Artificial Intelligence (AI) elements (Machine Learning (ML) + Forecasting) will make it possible to systematize the properties of materials by multiple parameters and will potentially allow to select more accurate parameters for Fatigue and Damage Tolerance analysis, minimizing the implementation of expensive experimental studies.

Main materials of the study. Although Artificial Intelligence (AI) has existed since the 1960s [6], the aviation industry only recently began to use it to optimize and improve aircraft performance.

Currently, there are few main applications of AI in civil aviation. The first application focuses on flight path optimization, accident prevention and operational efficiency [1], [3]. The second application involves optimizing aircraft maintenance and repair processes. Major airlines, such as Airbus, are actively incorporating AI technologies to enhance their maintenance procedures and prevent potential breakdowns. The third application is the analysis of large volumes of data. This capability enables airlines to make informed decisions based on accurate information, the Boeing company is utilizing AI for Spend management [4].

No data was found on the use of AI to assist in solving the aircraft design problems; apparently, companies consider their developments in this field a commercial secret and do not disclose the details of their projects. Regrettably, the application of AI in aircraft design or operation in Ukraine has also gone unnoticed.

To illustrate, the calculation of an airplane nose landing gear panel, which includes the elimination of corrosion and fastener type change is considered. Noted changes affected the stress concentration factor and reduce both the distance to the edge of the part and the spacing between the fasteners. Additionally, the only limited set of material information is available: static properties, Wohler's curve for particular values of stress concentration factors. Stress intensity factors, parameters of Walker, Paris and NASGRO equations, crack growth rate diagrams are not available for the material of interest but exist for the materials with different heat treatment.

The objective is to select the most appropriate parameters for calculating fatigue and crack growth by utilizing known material parameters and comparing them with the indirect characteristics of other materials.

The use of artificial intelligence to solve such a problem seems to be the most promising. There are three basic categories: Narrow AI (built for very specific tasks), General AI (more resembled to human capabilities), Artificial Super AI (machine is smarter than human in many fields. Super-intelligence is still a theory).

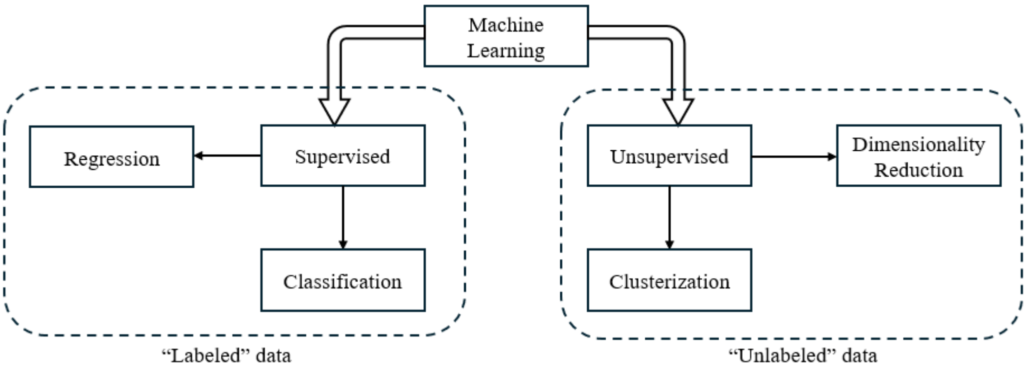


Figure 1 – Machine Learning (ML) classification

For the "first try", a narrow AI with supervised machine learning (ML) is to be selected to train the machine on multiple materials characteristics (or multiple classes of classification).

Multiple linear regression with multiple independent variables is to be used for classification:

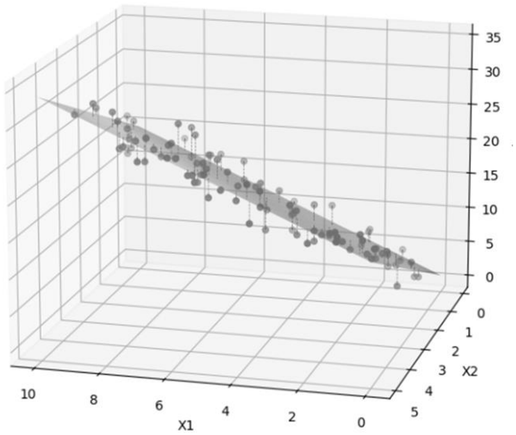


Figure 2 – Multiple Linear regression

Multiple linear regression may be expressed by the following equation [6]:

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i + \varepsilon \qquad (1)$$

Where y_i – is a predicted value, β_0 is the y-intercept, $\beta_1 \ldots \beta_i$ – regression coefficients, ε – model's random error.

Support vector machine (SVM), [6] is also considered as a promising method for classifying data in the given problem.

Deep learning and neural networks are also to be tested for this task even though they have several disadvantages: require large amounts of data, problems with interpretation and transparency: Neural networks, especially deep ones, operate as a "black box". They are complex multi-layered structures, which makes their results difficult to explain. The lack of transparency makes it difficult to understand how the network makes decisions which is critical for the aviation industry.

Conclusion. The primary options for using AI to address the challenges of fatigue calculation and crack growth prediction under conditions of limited information about material behavior during cyclic loading are outlined. This includes an overview of the main tasks and methods of machine learning.

Additionally, the advantages and disadvantages of each method of AI and ML for determining the durability of aircraft components will be the focus of further research.

References:

1. Anderson, T. (2017), Fracture Mechanics: Fundamentals and Applications, CRC Press
2. Artificial Intelligence and digitalization in aviation https://www.icao.int/Meetings/a40/Documents/WP/wp_268_en.pdf (access date: 06.11.2024)
3. AI At the Helm: Boeing’s Critical Turn Towards Nextgen Flight Safety https://www.forbes.com/sites/markminevich/2024/03/22/ai-at-the-helm-boeings-critical-turn-towards-nextgen-flight-safety (access date: 06.11.2024)
4. Artificial Intelligence at Boeing – Two Use Cases https://emerj.com/ai-power/artificial-intelligence-at-boeing (access date: 06.11.2024)
5. Ignatovich S., Karuskevich M., Maslak T., Yutskevich S. (2015), Resource and Durability of Aircraft, NAU
6. Posthoff, C. (2024), Artificial Intelligence for Everyone, Springer Nature Switzerland AG

UDC 629.7

Liulka V.

DEVELOPMENT OF AN EDUCATIONAL AND SCIENTIFIC SPACECRAFT FOR ULTRAVIOLET EXTRATERRESTRIAL ASTRONOMY

Statement of the problem. As interest grows in space-based ultraviolet (UV) astronomy, the challenge is to develop compact, affordable, and effective spacecraft for extraterrestrial observations. Traditional large-scale telescopes provide high-quality data but come at high costs and are less accessible for academic institutions. Recent technological advancements in CubeSat designs offer new possibilities for low-cost, small-scale space telescopes that can perform focused astronomical observations, such as exoplanet transit monitoring and UV studies of bright stars. The problem lies in maximizing scientific output within the constraints of CubeSat size, power, and stability while ensuring precise observational capabilities. This paper reviews and compares designs of CubeSat-based telescopes for UV and photometric studies of exoplanets and bright stars, with a focus on two notable implementations [1, 2].

Statement of the Main Materials of the Study. In the first study [1], the authors propose a 2U CubeSat designed to conduct photometric monitoring of exoplanetary transits across nearby bright stars. The satellite is equipped with a refractor telescope, featuring an 80 mm achromatic lens operating at f/5. The lens is coupled with a CCD camera with a resolution of 1600 × 1220 pixels, which enables high-quality imaging for precise photometric analysis. Images are transmitted to Earth via an FM transmitter at 437.465 MHz and a data rate of 9600 bps. The satellite includes a GPS for positional data and an attitude control and determination system (ADCS) featuring a three-axis gyroscope constructed with six reaction wheels, providing stable orientation essential for long-exposure imaging. The power consumption of this system is around 15 W, supplied by rechargeable lithium-ion/polymer batteries charged by solar panels. The optical tube of the telescope has a retractable design to maximize the compact 2U CubeSat volume constraints, specifically allowing only a 10 cm × 10 cm × 7 cm space for the optical elements. This innovative structural design, supported by an aluminum frame, represents a significant achievement in fitting high-quality optical systems into ultra-compact satellite formats.

The second study [2] presents a CubeSat-based telescope utilizing a modified off-axis segmented mirror design to increase light capture for UV observations. This telescope employs a 226.24 mm mirror as the primary, with dimensions carefully optimized for a rectangular CubeSat structure. The primary and secondary mirrors have dimensions of 80 mm × 80 mm and 41 mm × 24 mm, respectively, with a rectangular configuration to maximize light collection in the limited CubeSat space. This design demonstrates a creative approach to fitting larger optical components into CubeSat frames, enabling enhanced light-gathering capabilities crucial for UV astronomy.

Conclusions. Both CubeSat designs exemplify innovative engineering to overcome the spatial, power, and orientation constraints typical of small satellites. The refractor telescope with a retractable tube in the first study [1] and the off-axis mirror system in the second study [2] illustrate different approaches to maximizing observational potential within a CubeSat framework. These designs, if successfully implemented, could significantly contribute to UV astronomy by enabling long-term photometric and spectroscopic monitoring of bright stars and exoplanets. This, in turn, opens new educational opportunities by providing accessible and affordable satellite platforms for academic institutions and research groups to participate in space-based UV astronomy.

References:

1. Colín, A, Valdes-Sada, P, Olguín, L, Vázquez, R, López-Pérez, A, Cardona, JA, Villarreal-Méndez, M, Padilla, E, Calamaco, B, Gómez-Roa, A & Bermúdez-Reyes, B 2016, 'Implementation of an 80mm refractor telescope in a 2-U cubesat', *Proceedings of the International Astronautical Congress, IAC*, vol. 0.
2. Jin, Ho *et al.* (2013) "Optical Design of a Reflecting Telescope for CubeSat," *Journal of the Optical Society of Korea*. 한국광학회, 17(6), pp. 533–537.

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Mostovyi O., Arkhipov O.

THE USE OF ADDITIVE TECHNOLOGIES IN THE MANUFACTURE OF LIQUID-FUEL ROCKET ENGINES

Introduction. Additive manufacturing involves manufacturing techniques that add material to produce metal components, typically layer by layer. The significant growth of this technology is partly due to its commercial and operational advantages in the aerospace industry. The fundamental capabilities of additive manufacturing in the aerospace industry include: significant reductions in manufacturing costs and time, new materials and unique design solutions, component weight reduction through highly efficient and lightweight designs, and consolidation of multiple components to improve performance or manage risk, for example by internally cooling thermally stressed components or eliminating traditional joining processes. These capabilities are being commercialized in a wide range of aerospace applications, including liquid-fueled rocket engines.

Scientific and technical results. The use of heat exchange devices has significant potential to disrupt traditional aerospace manufacturing processes through the use of additive manufacturing methods due to their complex design and required internal characteristics. Manufacturing these devices using additive manufacturing can significantly reduce the number of parts, shorten lead times, lighten the design, and lower costs. For example, the GE9X heat exchanger boasts a 40% reduction in weight and a 25% reduction in cost, all while combining 163 components into a single part using additive manufacturing methods compared to traditional manufacturing methods [1].

The production of heat exchangers using additive manufacturing also has productivity advantages over traditional manufacturing methods. A demonstration sample of additive manufacturing of a rocket engine by Cellcore demonstrates the possibility of manufacturing a complex thrust chamber assembly in the IN718 engine with integrated lattice internal cooling channels [2]. NASA has also established a significant use of additive manufacturing for heat exchangers, such as combustion chambers of liquid rocket engines and channel-cooled nozzles.

A variety of applications have been reported, including combustion chambers using copper alloys such as GRCop-42, GRCop-42, C18150, as well as Inconel 718 and bimetallic copper-superalloy structures that have accumulated over 30,000 s and 400 hot fire launches. Channel-cooled nozzles made of various alloys, including JBK-75, NASA HR-1, Inconel 625, Haynes 230, and bimetallic (copper-superalloy) structures, have also been demonstrated by NASA and have accumulated more than 11,000 s and 250+ hotfire tests [3]. While these combustion chambers and nozzles meet performance requirements, they have also demonstrated significant cost savings and reduced equipment delivery times [4].

Typically constructed using multiple materials and thousands of components, combustion chambers, nozzles, and injector assemblies have recently attracted great interest for use in additive manufacturing for the production of single parts. An example of the use of additive manufacturing methods for the manufacture of single parts is the Aeon 1 rocket engine created by Relativity Space. The Aeon 1 engine, which will be launched on the future Terran 1 launch vehicle, has an injector, igniter, combustion chamber, and nozzle manufactured as a single component using additive manufacturing methods.

Conclusion. In conclusion, the integration of additive manufacturing techniques in the aerospace industry has proven to be a transformative force, revolutionizing traditional manufacturing processes and unlocking unprecedented capabilities. The fundamental advantages of this technology, including substantial reductions in manufacturing costs and time, the introduction of novel materials, and the realization of intricate design solutions, have positioned it at the forefront of innovation within the aerospace sector.

References:

1. General Electric - Additive, GE9X Engine Additive Parts, , https://www.ge.com/additive/sites/default/files/2020-08/GE9X Additive parts.pdf.

2. S. Donath, 3D printing a rocket engine, 2019. https://www.etmmonline.com/3d-printing-a-rocket-engine-a-886960/.

3. P.R. Gradl, C.S. Protz, Technology advancements for channel wall nozzle manufacturing in liquid rocket engines, Acta Astronaut. 174 (2020) 148–158, https://doi.org/10.1016/j.actaastro.2020.04.067.

4. P.R. Gradl, C.S. Protz, K. Cooper, D. Ellis, L.J. Evans, C. Garcia, GRCop-42 development and hot-fire testing using additive manufacturing powder bed fusion for channel-cooled combustion chambers, 2019. doi: 10.2514/6.2019- 4228.

UDC 629.7

Nikitin R., Konotop D.

CALIBRATION-BASED STRAIN GAUGE SETUP FOR MECHANICAL STRESS/STRAIN ESTIMATION

Statement of the problem. The basics of stress and strain measurement are well-explained in literature, but there are few simple guides for doing it with low-cost equipment. Big companies usually use special devices and software that are expensive and hard to get. Arduino projects have become popular because they're affordable and effective. However, finding clear information on using strain gauge sensors for stress and strain measurement is still difficult, even on Arduino forums. Our goal is to create an easy stress and strain measurement method using affordable hardware and simple software.

Statement of the main materials of the study. Strain Gauge Sensor. When the object deforms under stress, the strain gauge also deforms. If the object stretches, the gauge gets longer and thinner, increasing its electrical resistance. If the object compresses, the gauge gets shorter and thicker, decreasing its resistance.

Wheatstone bridge. The change in resistance is very small, so a Wheatstone bridge circuit is used to accurately detect this change. The bridge amplifies the tiny resistance variation and converts it into a measurable voltage change, which is proportional to the amount of strain. Wheatstone bridge setups are the following:

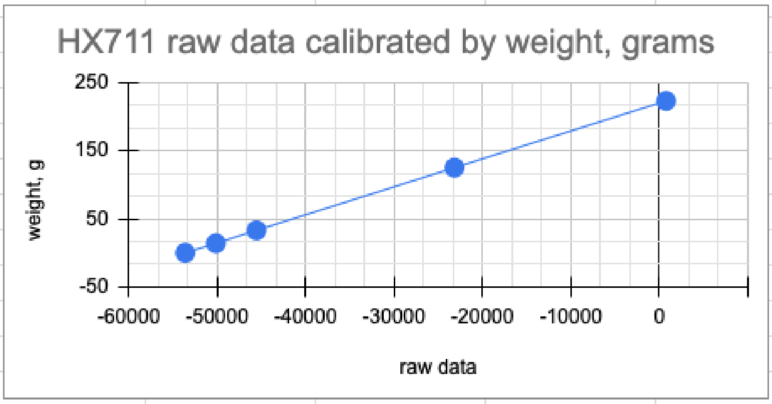
- *Quarter Bridge.* Uses one active strain gauge. It's simple and low-cost but less sensitive and more affected by temperature changes.
- *Half Bridge.* Uses two strain gauges, typically one in tension and one in compression. This setup improves sensitivity and provides some temperature compensation.
- *Full Bridge.* Uses four strain gauges, with two in tension and two in compression. It's the most sensitive and offers excellent temperature compensation, making it the most accurate configuration for strain measurement.

Load Cell. The load cell is a metal beam (often aluminum or steel) with strain gauges bonded to specific points on its surface. The strain gauges form a full Wheatstone bridge, allowing the small changes in resistance caused by bending to produce a measurable voltage output. The output voltage is calibrated to correspond to weight. This enables the load cell to translate mechanical bending into an electrical signal, which can then be displayed as weight on a scale.

Main Idea. The voltage signal correlates with the applied load within the elastic region of the stress-strain curve. We propose utilizing this principle to calibrate strain gauge sensors, emphasizing calibration based on stress rather than weight. This approach will be explored in further research. In the current study, we calibrated the system using a known weight (applied load) to establish a linear regression function, demonstrating its ability to estimate unknown loads. Refer to the following figure for further details.

raw data	weight, g
-53600	0
-50140	14
-45550	33
-23170	125
750	223

Y = 0.0041X + 219.989



Conclusions. The calibration method for strain gauge sensors using a known load to estimate an unknown load through linear regression proved effective. Linear regression is optimal as it reflects the physical relationship of stress-strain dependency within the elastic region for metallic structures. This calibration approach is also expected to yield reliable results when using a known stress to determine an unknown stress under random or inaccurately measured loads.

References:

1. Dally, J.W. and Riley, W.F., 1991. Experimental stress analysis. 4th ed. New York: McGraw-Hill.

2. Inman, D.J., Farrar, C.R., Lopes, V., and Steffen, V., 2005. Damage prognosis: for aerospace, civil and mechanical systems. 1st ed. Chichester: John Wiley & Sons.

3. Roesler, J., Harders, H. and Baeker, M., 2007. Mechanical behaviour of engineering materials: metals, ceramics, polymers, and composites. 1st ed. Berlin: Springer.

4. Farrar, C.R. and Worden, K., 2012. Structural health monitoring: a machine learning perspective. 1st ed. Chichester: John Wiley & Sons.

5. Boller, C., Chang, F.-K., and Fujino, Y., 2009. Encyclopedia of structural health monitoring. 1st ed. Chichester: John Wiley & Sons.

UDC 004.8

Pashistiy B., Larkov S.

THERMAL CONTROL SYSTEM FOR ON-BOARD EQUIPMENT OF MOTOR GLIDERS FOR FLIGHTS IN THE STRATOSPHERE

Introduction. In recent years, the need to study the atmosphere and Earth's surface from an aerial perspective has grown significantly. So far, most of these tasks have been addressed through the use of satellites for a wide range of purposes. However, as shown by the current situation in Ukraine, it is crucial to rely on our own scientific and technical capabilities for research and observation. Ukraine has launched relatively few satellites in recent years, and even those do not provide all the required data. Satellites present a major challenge due to their complexity, high launch costs, and limited access to launch opportunities. Consequently, the use of drones for stratospheric research appears as a logical solution, enabling data collection from multiple perspectives. Developing such systems is inherently complex, requiring a comprehensive approach from engineers. This text will, therefore, focus on the issue of thermal management.

Scientific and technical results. In this section, we will outline the key points and phases of UAV flight under consideration. Preliminary studies have shown that the latest technologies can significantly reduce the geometric dimensions of a UAV for high-altitude research, so an electric airframe with a wingspan of 3200 mm, fuselage length of 1535 mm and a total weight of up to 3.2 kg [1] was chosen to maintain altitude and carry the necessary equipment on board. Since this UAV cannot climb to the required altitude on its own, it must be transported to the take-off point by alternative means, in our case an atmospheric balloon. This makes it necessary for the drone to stay in standby mode in very difficult conditions. After that, the UAV starts up its systems and begins to generate heat. Thus, we have two similar but polarly different thermal management tasks: Heat preservation and Flight mode

1) Heat preservation: this calculation includes determining the heat transfer from warm equipment to cold outside air. In this way, we calculate a system of thermodynamic equations that allow us to study the temperature drop of each of the elements of the instrument compartment, namely: the temperature of the equipment (the equipment is taken in a generalized way, namely, we consider it as a single heated space, which allows us to simplify calculations without losing their accuracy), after which we calculate the air temperature in the case, as well as its thermal conductivity characteristics, transient processes from the internal air to the wall, the passage through the walls and, accordingly, the heat output from the wall to the external space. By solving this problem, we can observe how the temperature of the equipment will gradually drop over time, which will be used to calculate the required layer of thermal insulation, which will allow us to protect the system from overcooling for the required period of time. We will consider overcooling to be the lowest possible temperature for each element of the compartment. Electronics used in this project can maintain full functionality at temperatures down to -10°C [2]. It is also worth noting that to achieve the best results, it would be great to provide a passive energy-saving system that will

significantly save battery power and extend the useful flight time. However, if it is not possible to provide it, it is possible to use both electric and chemical heating.

2) Flight mode: here our electronics will actively radiate heat, so the risk of overcooling disappears, but another and no less dangerous one arises, and that is overheating. In the previous step, we made a case that perfectly ensures the preservation of heat inside it, but now it plays exclusively against us. Thus, in conditions of low air density, convection works much worse, and most of the radiation remains [3]. It is also worth remembering that in the higher atmosphere, the influence of the sun and the earth's albedo is much higher, which together increases the complexity of the problem. From now on, our task is to determine the upper thermal limit of our electronics and to understand whether our case radiates enough heat into the atmosphere. Mathematically, our task becomes more complex, and accordingly, there are many more factors of influence

It is worth mentioning that any calculations need to be confirmed, so physical testing in a cold chamber is very important, as theoretical thermal models often show discrepancies due to the discrepancy between the generalized statements of thermal characteristics and the actual ones, and the processes of heat transfer in reality are much more complex than in the calculation models, so there is always a need to introduce correction factors.

Conclusion. Therefore, there is an obvious need to develop high-altitude unmanned aerial vehicles (UAVs) for atmospheric and ground observations, which will significantly expand the capabilities of Ukrainian specialists in the field of meteorological research. However, the creation of such UAVs requires significant scientific and engineering efforts due to the complexity of the system and the lack of generally accepted standards for its design and calculation. Effective thermal management is essential to ensure the reliable operation of all onboard systems under various conditions.

References:

1. TopModelCZ. (n.d.) *Ideal AL matice návod web*. Available at: https://www.topmodelcz.cz/resources/upload/data/204_Ideal%20AL%20matice%20n%E1vod%20web.pdf (Accessed: 4 November 2024).

2. Ortega, C.B. (n.d.) *Thermal Management of Electrical Systems in a Solar-Electric Stratosphere HALE*. Institute of System Dynamics and Control, German Aerospace Center (DLR), Oberpfaffenhofen, Bayern, 82234, Germany.

3. Liles, K. and Amundsen, R. (n.d.) *NASA Passive Thermal Control Engineering Guidebook*. NASA Engineering and Safety Center (NESC) Passive Thermal Technical Discipline Team (TDT).

UDC. 629.783

Pawłowski K.

INTEGRATION OF AERIAL PHOTOGRAMMETRY AND MACHINE LEARNING FOR RAILWAY TRACKS MONITORING SYSTEM

Introduction. Rapid development of technology and its accessibility across last 20 years has enabled introduction of completely new solutions to certain branches of industry. One such example is aerial photogrammetry and machine learning. When combined together, automation of numerous problems becomes possible. As it currently stands, the railway review is conducted manually. The employee walks or drives along the tracks and takes photographies of the infrastructure. Following that, the assessment of the quality of various elements as well as formulating report is performed by hand as well. Both those parts can be automated by taking pictures using drones and using computer vision to generate infrastructure report.

Scientific and technical results. When dealing with Computer Vision (CV) it is impossible not to mention machine learning (ML). This is why short introduction to it is necessary. ML in the most simple way can be described as process of extracting knowledge from data. It uses combined knowledge from statistics, computer science and artificial intelligence. ML is frequently referred to as statistical learning or predictive analytics. In general, ML can be divided into two major categories : supervised and unsupervised. The prior one consists of two subdivisions : classification and regression.

In supervised learning, the algorithm is provided input data and corresponding outputs. In classification problems, the outputs are called labels and there should be finite numbers of them. For example, the algorithm should tell whether a photo presents a cat or a dog. In a regression problem, the outputs are numbers and the goal is to predict a certain value, so the number of possible outputs is possibly infinite. This can be used when predicting a person's salary based on their age, profession, experience and city they live in. Unsupervised learning is a situation where only inputs are known. Then the code tries to find some relations and possibly create several categories to which a single data point can belong. This is widely used in anomaly detection by banks.

Vision, both human's and computer's, consists of two major components. First one is the sensing device. It captures as much information as possible from the environment as possible. People use their eyes to capture light. This information is then passed to the brain using neurons. Cameras capture light as well and transfer the light to the computer through the pixels. Machines are far superior at this stage as the modern technology allows for capturing more detailed images, from bigger distances and on more frequencies (ex. Infrared).

The second one is the interpreting device. This is where the information from the picture is processed and the meaning of it has to be found. People are able to do this on multiple different levels in a matter of seconds. Computers are still lagging behind on this matter. The computer vision problem, even though it has made significant progress in the last years, is still considered unsolved due to this.

To understand how ‘intelligent’ connections are made from such form, several concepts should be firstly introduced, as they are universally used in various CV problems.

Artificial Neural Network (ANN) is an approach based on human brain. Multiple neurons are created and information is passed between each one.

Single neuron or perceptron is capable of taking several inputs and producing the output based on the weighted summation. The basic workflow is that the input is taken and then multiplied by associated weight. Then all of those are added up and this sum is passed through an activation function, which determines the output. Weights are determined during the testing phase and most of the time are generated automatically. Collection of multiple neurons and activation functions is the ANN. All layers of perceptrons and their respective connections are considered a hidden layer, which along with input and output layer forms the entire model. Most of the times, multiple layers of neurons are used and outputs from the first one are used as inputs in the subsequent one. This number is one of the hyperparameters used to tune and optimize the simulation.

Convolutional Neural Network (CNN) is a kind of ANN but specialised in an image processing. Due to large sizes of digital images, standard approach would be too complex to compute, as extensive number of pixels produce overwhelming number of connections and weights (in ANN each neuron is connected to each perceptron in a subsequent layer). CNN solves this problem, significantly reducing size of the input and number of unique connections before performing calculations. Standard architecture consists of three main parts : convolutional layer, pooling layer and fully connected layer.

The railway monitoring system, with automated report generation falls under the object detection category. The focus is to spot infrastructure objects in the pictures and count them, so image classification is not sufficient. Below are several widely used algorithms in CV.

YOLO stands for You Only Look Once. At its core, this method is rather simple. It treats object detection more as regression problem, rather than classification. The first thing YOLO does is division of input into the grid boxes of equal shapes. Then, CNN is used to access probability of each of them containing target object. Squares with 0 score are taken out of the consideration at this step. Following that, regression module is used to predict bounding boxes.

R-CNN has been developed by Ross Girshick in 2014 as a new way of dealing with object detection problems. The core of the algorithm is usage of so called Selective search instead of Exhaustive search that has been used to that moment. It takes advantage of object segmentation. At first, numerous region proposals are generated (around 2000). Later CNN is applied to each region individually to estimate feature representation. This outputs a feature vector from each segment, which are later passed through SVM (Support Vector Machines). The proposed boxes are than classified, and regression is performed on bounding boxes to adjust their dimensions to better fit target object.

Single Shot MultiBox Selector (SSD) is one of the fastest algorithms available nowadays and prevails when it comes down to real-time operation. Its speed comes from the fact that it combines classification and localisation In a single pass. At the backbone, SSD has a CNN network, usually pre-trained, to be used as feature map extractor. Multiple feature maps are generated at progressively lower resolutions. First ones have higher resolutions and are used to capture small objects, while the last ones extract large objects. Each map is divided into cells that contain pre-defined bounding boxes with various aspect ratios and shapes. Those are than compared to ground truth boxes to calculate the Intersection over Union (IoU) scores. Following that, SSD calculates class confidence and box offsets in a single step. Those describe probability scores for each class, with background class including no detectable object included, and required adjustment vectors for each cell respectively.

Weakly Supervised Object Detection (WSOD) is an interesting take on object detection, when labelled training data is unavailable and would prove too time-consuming to be created by a programmer. Instead of relying on tagged bounding boxes it rather takes image-level labels, informing what objects are present in the picture but without specifying where. Most of the time, WSOD uses Multiple Instance Learning (MIL) methods to try and predict regions that could possibly contain target. Then, model determines which boxes are most likely to match the position of labelled objects by maximizing the probability that boxes containing object are correctly interpreted as such.

Conclusion. Computer Vision, while relatively new, has already made huge impact on modern world technology and can be further implemented in industrial problems to automate some time-consuming processes. With ML at its core, even most complex object detection problems can be solved with appropriate training data and adequate model chosen.

As for the railway track problem the images do not need to be processed in real-time, faster algorithms with lower accuracy are not worth implementing. This is why for the future considerations, YOLO and R-CNN algorithms will be used on real-life data to access which one would be the best for the final application.

References:

1. Ronny Francis Ribeiro Junior , Guilherme Ferreira Gomes (2023). On the Use of Machine Learning for Damage Assessment in Composite Structures: A Review
2. António J. R. Neves, Bruno Barbosa, Sandra C Soares, Isabel Dimas (2018). Analysis of Emotions From Body Postures Based on Digital Imaging
3. Rajalingappaa Shanmugamani (2018). Deep Learning for Computer Vision

UDC 536.24

Plisetska E., Lobunko O.

CHANGES AND ENHANCEMENTS IN SPACECRAFT THERMAL PROTECTION SYSTEMS

Introduction. The challenge of changing and improving spacecraft thermal protection systems (TPS) is the need to continuously improve the efficiency of materials and structures to meet the new requirements of modern missions. Advances in the space industry have led to the need for TPS that provide not only reliable one-time protection, but also reusability, resistance to higher temperatures and reduced weight to reduce launch costs. In addition, the development of commercial space missions requires cost-effective, versatile systems that can be adapted to different types of vehicles and environments.

Scientific and technical results. Disposable ablative TPSs were standard in early spacecraft because of their simplicity and efficiency. These materials decompose upon re-entry, and the resulting gases cool the boundary layer and protect the spacecraft from excessive heat. One example is AVCOAT-5026-HCG, a low-density ablative heat shielding material consisting of epoxy resin encrusted with silica fibres and phenolic microspheres. There are two versions of this ablation. Where the honeycomb matrix version was used in the Apollo command module, and the other, made of moulded blocks, was used on Orion Artemis 1 (Crouch & Walberg 1969).

It may be assumed that this material is no longer in use. However, even the most recent missions, such as the Mars Science Laboratory and the new SpaceX Dragon modules, use improved Phenolic Carbon Ablator (PICA). This material can withstand peak heating rates of up to 1200 W/cm². These features are due to the structure of PICA, which consists of carbon fibre impregnated with phenolic resin, creating a lightweight but highly effective abrasive layer. SpaceX has further improved this thermal protection by adding a phenolic resin-impregnated carbon felt backing attached to the spacecraft's structural panels and filling between them to form a seamless heat shield (Nowlin & Thimons 2013).

Ablation TPS variants include Silicone synthetic foam again for SpaceX Dragon and other missions. This foam is a silicone syntactic foam with radio transparency that enables signal transmission in high-temperature conditions. Another company, Boeing, has a lightweight ablator (BLA) used in the CST-100 heat shield, which consists of a silicone resin that fills a honeycomb-like structure. This design minimises the weight of the heat shield while maintaining its ability to dissipate heat during re-entry effectively. Among the newest materials of this type is Pyron, which is used on the SpaceX Falcon and consists of carbon felt with a heat-shielding coating (Bouslog 2023).

The need to save material and use it more efficiently has led to the development of reusable TPS. The most famous example of this type of application is NASA's Space Shuttle Orbiter, which has made 135 flights with this technology. The primary protection is provided by high-temperature tiles, which include materials based on silica fibre, such as HRSI, LI2200, FRCI-12, and BRI-18, capable of withstanding temperatures above 1200°C. Modern advances have made it possible to introduce modern tiles, such as AETB/BRI, which combine silica and aluminium fibres with more robust, more rigid coatings, such as TUFI (Toughened Uni-piece Fibrous Insulation). High-temperature blankets, represented by Advanced Flexible Reusable Surface Insulation (AFRSI), which is made of a cross-linked ceramic fabric and quartz fibre batting, are an exciting solution for protecting areas with lower temperature exposure and can withstand temperatures up to 1000°C. The other type is felt reusable surface insulation (FRSI), which uses a silicone coating and can withstand temperatures up to 450°C. In turn, the US Air Force X-37B aircraft improved on this technology by creating TUFROC (Toughened Uni-piece Fibrous Reinforced Oxidation-Resistant Composite) tiles that can withstand temperatures around 1700°C (Palharini 2014).

In parallel with these main types of TPS, alternatives have been developed that are less popular due to their specific characteristics and limited range of applications but are worthy of attention: heat sinks, heat pipes and transpiration. A heat sink is a system where the heat generated on the surface by aerodynamic heating is transferred deep into the structure, which is stored in a graphite composite with a high heat capacity. This TPS was used on the experimental X-15 aircraft, but this technology has a limited ability to absorb large amounts of heat without overheating, which does not make it suitable for use in modern space systems. Heat Pipe, in turn, is a closed system with a liquid coolant (depending on the temperature, it can be either ammonia/sodium or caesium/potassium) that evaporates when the surface is heated, transfers heat through convection and condenses in the cooled parts of the system. However, due to the complexity of its design and insufficient efficiency, this technology is not widely used in the aerospace industry. Transpiration Cooling involves a coolant (water, hydrogen or helium) flowing through a porous material (porous graphite or ceramic composites), evaporating and creating a barrier layer between the hot surface and the environment, which reduces the surface temperature. Similarly, this system is difficult to manufacture and control the flow, so it has yet to be used in hypersonic vehicle systems as expected (Modlin 1991).

During the intensive development, TPSs were also produced but never used in practice, including metal panels for the X-33 project, which included a metal plate with an integrated insulation package. This technology may have found its use, but it was abandoned due to the closure of the project. An exciting development is the body flap for NASA's X-38, consisting of a carbon-carbide-silicon-coated composite. However, it is not used for a similar reason, although this material became the basis for the TPS elements of ESA's IXV spacecraft. Another noteworthy feature is the flexible TPS, which consists of Nextel fabric with Pyrogel insulating layers and a gas barrier layer. This technology provides high-temperature resistance and shape adaptability during aerodynamic braking at hypersonic speeds (Blosser 2000; Bouslog 2023).

The challenge of changing and improving spacecraft TPS is the need to continuously improve the efficiency of materials and structures to meet the new requirements of modern missions. Advances in the space industry have led to the need for TPS that provide reliable one-time protection, reusability, resistance to higher temperatures and reduced weight to reduce launch costs. In addition, developing commercial space missions requires cost-effective, versatile systems that can be adapted to different types of vehicles and environments.

Conclusion. The evolution of spacecraft thermal protection systems meets the new requirements of modern missions. From single-use ablation TPS to reusable systems, the focus has shifted to materials with improved thermal performance, low weight and increased durability. Modern TPSs provide reliable protection while optimising launch costs and are adaptable to different mission environments, which is critical for developing commercial and scientific programmes.

References:

1. Crouch, R.K. & Walberg, G.D. 1969, 'An Investigation of Ablation Behavior of Avcoat 5026/39M Over a Wide Range of Thermal Environments', NASA Technical Memorandum X-1778, viewed 7 November 2024, https://ntrs.nasa.gov/search.jsp?R=19690013568.

2. Nowlin, S. & Thimons, L. 2013, 'Surviving the Heat: The Application of Phenolic Impregnated Carbon Ablators', University of Pittsburgh Swanson School of Engineering, viewed 7 November 2024, https://spacex.com.pl/files/2017-11/pica-x.pdf.

3. Bouslog, S. 2023, 'Thermal Protection Systems: State of the Industry', NASA Technical Reports Server, viewed 7 November 2024, https://ntrs.nasa.gov/api/citations/20230015883/downloads/TPS-StateofInd-SAMPE-Final2.pdf.

4.Palharini, R.C. 2014, 'Atmospheric Reentry Modelling Using an Open-Source DSMC Code', PhD thesis, University of Strathclyde, viewed 7 November 2024, https://stax.strath.ac.uk/concern/theses/2801pg37r.

5. Modlin, J.M. 1991, 'Hypersonic Aerospace Vehicle Leading-Edge Cooling Using Heat-Pipe, Transpiration and Film-Cooling Techniques', PhD thesis, Georgia Institute of Technology, viewed 7 November 2024, https://www.osti.gov/biblio/7109614.

6. Blosser, M.L. 2000, 'Development of Metallic Thermal Protection Systems for the Reusable Launch Vehicle', Journal of Spacecraft and Rockets, vol. 37, no. 5, pp. 662–669, viewed 7 November 2024, https://arc.aiaa.org/doi/10.2514/2.3610.

UDC 629.7

Puziuk K., Kopyt A.

RESEARCH ON THE IMPACT OF PILOT TRAINING LEVEL ONREACTION TIME DURING IN-FLIGHT EMERGENCY SITUATIONS

Introduction. Contemporarily, research on pilots' reaction times and behaviors within the aircraft cockpit represents a critical area of analysis, with substantial implications for aviation safety and process optimization. Eye trackers - devices that monitor eye movements - enable efficient research in this field.

Information on where and how quickly a pilot's gaze is directed is essential for understanding perception during the most crucial phases of flight. The reaction time of an aircraft pilot is of paramount importance, as delays in interpreting alarms or messages can pose significant risks. A study was therefore undertaken to examine the reaction time of pilots with varying levels of training, with the aim of exploring the correlation between training and response speed.

Scientific and technical results. The eye-tracking device used during the test will be the Tobii Pro Nano. It is a stationary type of eye-tracker, which provides data at a frequency of 60Hz. The device calibration is very simple and is carried out using the Tobii Pro Eye Tracker Manager software. It involves sequentially displaying five points on the screen. The person performing the calibration should focus their gaze on each point. A correctly executed calibration will reduce the device's possible errors.

The planned study will be conducted on a Boeing 737 MAX simulator. An eye-tracking device will be installed in the cockpit and adapted to function in it. Data from the tests will be collected and processed using custom software developed by the author in MATLAB and the Simulink environment.

The participants in the experiment will include:

- A professional Boeing airline pilot
- A professional Embraer airline pilot
- A pilot holding Private Pilot License (PPL(A))
- An individual without any piloting qualifications or experience

The first stage of the study will be selecting the emergency situation scenario that will be simulated during tests. Afterwards, a task will be decided on to be performed during test.

Before starting the simulation, each participant will calibrate the device independently to ensure the results are as accurate as possible. Participants will also be able to fly on the simulator for 10 minutes to get used to the cockpit.

During the actual test, each participant will perform the same task three times. This will ensure that the obtained results are reliable and valid.

After the experiment is completed the collected data of their reaction time and gaze fixation points will be compared and analyzed. The end results will be presented and discussed with the pilots, so that they are aware of their capabilities and gain valuable information about their performance in cockpit.

Conclusion. The conducted research will undoubtedly provide valuable insights into pilot behavior in the cockpit. It will allow for the determination of whether the type and level of flight training they have undergone significantly impact their reaction time and ability to maintain full focus in a challenging situation. Such studies, when conducted on a larger scale, undoubtedly contribute to improving the level of flight training, and consequently, aviation safety.

References:

1. Barkhuizen, W., Schepers, J. and Coetzee, J. (2002), "RATE OF INFORMATION PROCESSING AND REACTION TIME OF AIRCRAFT PILOTS AND NON-PILOTS"

2. Saniewski-Dźwigaj, P. (2024), "Analysis of the Impact of Task Complexity on Response Time Using Eye-Tracking Technology"

3. Zheng, Y., Lu, Y., Jie, Y., Zhao, Z., Fu, S. (2023) "Test pilot and airline pilot differences in facing unexpected events. Aerosp Med Hum Perform."

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Rymzha A., Zinchenko D.

RESEARCH AND ANALYSIS OF THE LATEST ENGINEERING SOLUTIONS IN THE DEVELOPMENT OF ANNULAR WINGS

Introduction. Annular wings, characterized by their ring-like structures, offer unique aerodynamic benefits, including reduced induced drag and enhanced lift characteristics. In recent years, advances in computational fluid dynamics (CFD), materials science, and manufacturing techniques have enabled significant progress in annular wing design. This thesis explores the latest engineering solutions in annular wing development, design challenges, and practical implementations highlights the growing relevance of annular wings in modern aeronautics.

Research and Analysis. In recent years, winglets and closed-wing configurations have gained significant traction within the aviation industry, with leading aerospace companies exploring diverse applications of these advanced aerodynamic features. Prominent industry players, including Lockheed Martin, have introduced designs that incorporate variations of closed-wing systems, such as the PrandtlPane configuration. These advancements strongly suggest that the future of large-scale aviation may increasingly integrate closed-wing configurations, either partially or entirely.

One notable area of research is in urban air mobility (UAM) solutions, especially air taxis, which are set to revolutionize urban transportation. For instance, Jetoptera [2] has embarked on an ambitious design for a high-speed vertical take-off and landing (HSVTOL) aircraft with a propellerless propulsion system, aiming for transonic speeds—a goal facilitated by Prandtl’s closed-wing design. This configuration enhances aerodynamic efficiency and stability, expanding the potential of VTOL aircraft to meet UAM demands.

Unmanned aerial vehicle (UAV) technology also opens new doors for innovative aircraft configurations. VTOL Aerospace, formerly Elytron Aircraft, has pioneered closed-wing tiltrotor designs that integrate the vertical lift capability of helicopters with the range and fuel efficiency of fixed-wing aircraft. Their latest model, the Converticopter [3], is a compact UAV developed for government and commercial applications, including search and rescue, border surveillance, and infrastructure inspections. With its closed-wing design and dual tiltrotors, the Converticopter achieves impressive endurance—up to 1.5 hours with a 20-Ah battery, extendable to over five hours with a hybrid system—making it exceptionally capable for prolonged missions.

The field of annular-wing design is evolving, with engineers increasingly exploring the integration of multiple aerodynamic schemes. This approach enables hybrid designs which combine not only the classic circular wing, but also create new configurations. For example, it is possible to combine a straight wing with a circular wing, or a delta-annular wing (although the latter has not found wide application in practice yet). Such innovative solutions open up new prospects for achieving optimal aerodynamic performance, reducing drag and increasing flight efficiency.

One of the newest applications of an hybrid annular scheme is the American V-BAT drone, which combines straight wing with the ring impeller and was already used effectively on the Ukrainian frontlines. The vertical takeoff capability provides Ukrainian forces with mobility and efficiency. In addition, the V-BAT is capable of not only transmitting targeting data, but also assessing combat damage, which helps to maximize the use of available resources and increase the overall effectiveness of combat operations [4].

Conclusion. The exploration and development of annular and closed-wing configurations have opened new ways in aerodynamics, offering notable advantages in terms of drag reduction, lift enhancement, and operational efficiency. Through advancements in computational modeling, materials science, and precision manufacturing, annular-wing designs have evolved from theoretical concepts to practical applications in both manned and unmanned aircraft. From the potential to transform urban air mobility with high-speed VTOL aircraft to enabling more resilient UAVs for specialized missions, annular wings present compelling benefits that align with the aviation industry's goals for enhanced performance, reduced environmental impact, and greater safety.

As research continues to investigate and validate the aerodynamic advantages of ring-wing systems, annular wings are positioned to play a vital role in next-generation aviation technologies.

References:

1. Mehmood, K., Shahzad, A., Qadri M.N.M., Salamat S., Shams T.A. and Masud J., 2023. Flow physics of annular and semi-annular fanjet and integration scheme with aircraft wing. *Physics of Fluids*, 35(9), p.097101. Available at: https://doi.org/10.1063/5.0165058

2. Lavars N., 2023. *Jetoptera aims for transonic speeds with bladeless HSVTOL aircraft*. New Atlas. Available at: https://newatlas.com/aircraft/jetoptera-bladeless-hsvtol/

3. McGarrah L., 2017. *Converticopter UAV blends VTOL with fixed-wing efficiency*. New Atlas. Available at: https://newatlas.com/converticopter-uav-vtol-aerospace/51128/

4. Tucker P., 2024. *US-made, jam-resistant drones are helping Ukrainians cut through Russian EW*. Defense One. Available at: https://www.defenseone.com/technology/2024/10/us-made-jam-resistant-drones-are-helping-ukrainians-cut-through-russia-ew/400735/

UDC 629.7

Sandu M., Konotop D.

OPTIMISING A HIGH-PRESSURE TURBINE BLADE

Introduction. Despite the fact that global aviation is going through a difficult time due to the COVID-19 pandemic, which has significantly reduced the number of air travel, in 2022 the number of air passengers almost reached 7 billion, which is 53.5% more than in 2021. This is equivalent to 73.8% compared to 2019, which indicates that the number of flights will soon exceed the pre-pandemic statistics [2]. Due to the constant growth in the number of air travel, the volume of CO2 emissions into the atmosphere is also increasing, with the aviation industry accounting for about 2-3% of global emissions. In 2021, IATA members adopted a resolution to reduce CO2 emissions to zero by 2050 [1]. There are several ways to solve this problem, the most popular being the transition of aircraft to electric engines, but the biggest problem with such engines is that they are too bulky and heavy and cannot provide enough energy for efficient and long journeys [3]. Scientists and engineers around the world are also focused on inventing more environmentally friendly aviation fuels, which is the second solution to the problem [4][5]. The method that will be considered is to modify an existing propulsion system, namely to increase its efficiency, which will allow it to fly the same distance using less fuel. This method is a more affordable and faster solution than the first two, the creation of a fully environmentally friendly fuel and the development of an electric aircraft capable of long-distance flights.

The aim of this work is to create a modification of the AN-124 powerplant from ANTONOV Company. This aircraft is designed to transport bulky, super-heavy or simply unique (which can often be classified as oversized) baggage. A comparison of the aircraft before and after the modification will be made, including flight and economic parameters.

The optimisation will be to improve the aerodynamic performance of the blade, primarily focusing on increasing the lift coefficient of the existing blade.

To do this, we need to know the aerodynamic characteristics of the high-pressure turbine blade that is installed in the D-18T. Having obtained the real model, we used reverse engineering technology to create a non-parametrized 3D model. Now, the profile of this blade can be optimised using software such as Rhinoceros 5, namely, to change the profile, thereby changing the characteristics.

However, improvements can be made not only by improving aerodynamic performance, but also by raising the temperature ceiling that the turbine blade can withstand. There are usually two ways to do this:

1. Using or improving the thermal protection coating (TPC);

2. Changing the alloy to a more heat-resistant one without losing heat-

1. Two types of heat-protective coatings are commonly used, namely columnar and lamelliar structures. The former has better heat resistance characteristics, so it is used in moving parts of the hot engine path, and the latter has better heat resistance characteristics, so it is mostly used for the combustion chamber and guide apparatus of a high-pressure turbine.

2. Currently, the D-18T uses the ЖС6-К alloy to manufacture the high-pressure turbine blade, but to improve the heat-resistant and heat-resistant characteristics, it is necessary to use a more modern alloy, for example, a supernickel alloy - Inconel, which is often used in modern aircraft engines for high-pressure turbine blades.

Conclusion. The main part of the work is to modify the existing power plant by improving the turbine's efficiency. To do this, a new blade configuration will be developed in the high-pressure zone to improve its aerodynamic quality. An overview study will be carried out on the materials and alloys that can replace nickel alloys without losing heat resistance and heat resistance, what blade coating should be used, and what production technology is optimal for achieving the goal (increasing engine efficiency, which will reduce fuel consumption). The impact of blade changes in the high-pressure zone on engine performance and aircraft performance will be investigated.

References:

1. Ihor Burdyga Global aviation to reduce CO2 emissions to zero URL: https://www.dw.com/uk/svitova-aviatsiia-prahnutyme-skorotyty-vykydy-co2-do-nulia/a-59402583
2. Graham Dunn Global airport passenger numbers in 2022 reached 74% of pre-pandemic highs URL: https://www.flightglobal.com/networks/global-airport-passenger-numbers-in-2022-reached-74-of-pre-pandemic-highs/152767.article
3. Andreas Spaeth Are electric planes ready for takeoff? URL: https://www.dw.com/en/are-electric-planes-ready-for-takeoff/a-64491147
4. Elissa Garay The world`s eco conscious airlines URL: https://edition.cnn.com/travel/world-most-eco-conscious-airlines-cmd/index.html
5. V. M. Isayenko, S. V. Boichenko, K. O. Babikova, O. O. Vovk ‘Environmental protection in air transport processes’ National Aviation University 2016. 245-252 p.

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Saz K., Ortamevzi G.

STRENGTH OF MAIN LANDING RIMS ACCORDING TO TIRE PRESSURE

Introduction. In this study, the main landing gear rim of an experimental aircraft according to different tire pressures was analyzed using the finite element method. The main landing gear consisting of two parts is modeled in 3D and the mathematical model was created for the analysis of its strength. Through this mathematical model, strength parameters are determined by stress and safety factor according to tire pressure. [1][2][3][4]

Materials and Methods. It is necessary to determine the rim -compatible tire to be used in the main landing set of the experimental aircraft or to determine the thickness spectrum of the tires to be used. The strength of the rim, especially the tire seating surfaces and rim ribs, is important. In this study, Stainless Steel was used as a rim material in terms of corrosion protection and strength.[5][6] The 3D model of the rim is shown in Figure 1.

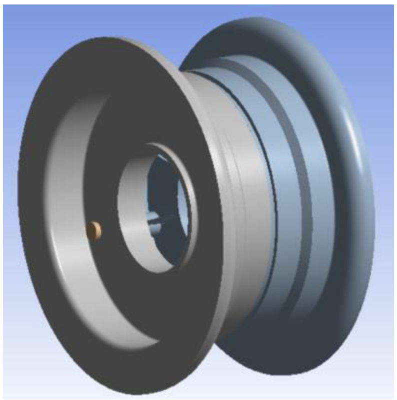


Figure 1 - 3D model of rim

The rim tire seating surfaces and ribs focused on strength analysis were frequently meshed and a mathematical model was created.[7] The mathematical model is shown in Figure 2.

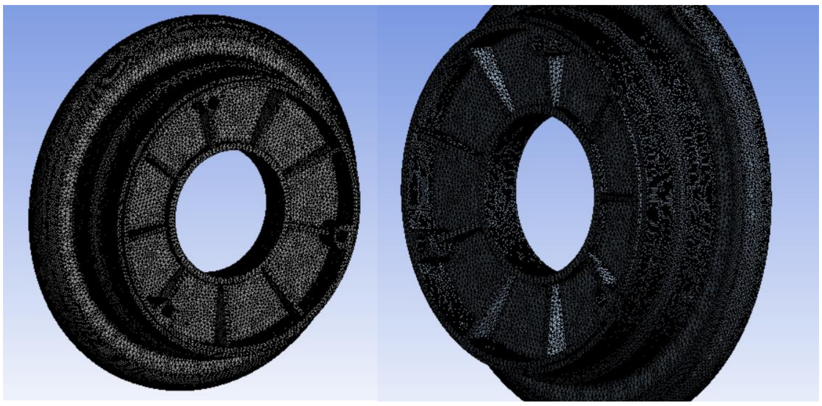


Figure 2 - Mathematical model of rim

Results and Discussion. The air pressure to be formed in the rim is applied to the tire seating surfaces at 3,75- 4,5 MPa in the extreme case. Stress in left-side rim and right-side rim ribs formed an analogically similar values. The stress values are between 143-88 MPa for 3,75 MPa, while safety factor is between 2,44-2,97, examining the regions that are open to the notching effect of the rim ribs that are available for critical breakage. When the air pressure value is applied to the tire seating surface of 4,5 MPa, the stress values in the same regions between 164-106 MPa are located, while safety factor decreases to the range of 1,47-2,74. Figure 3 and 4 shows the stress and safety factor distribution of the regions analyzed when the pressure simulated at the value of 3,75 MPa.

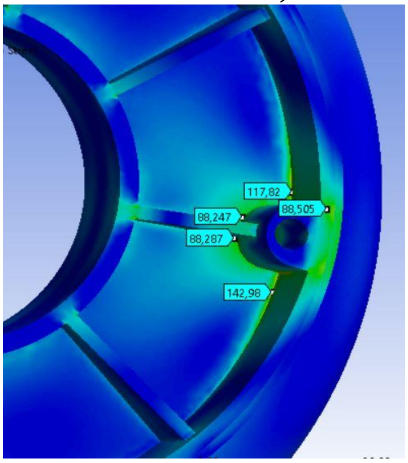


Figure 3 - Stress Distribution

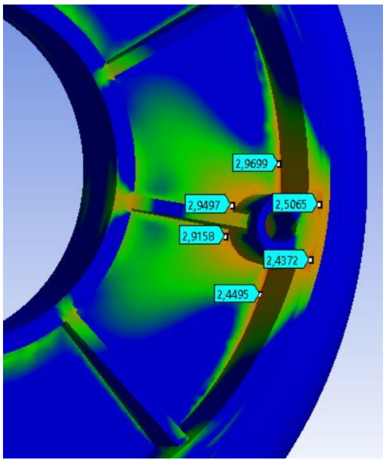


Figure 4 - Safety Factor Distribution

Conclusion.

1. Apart from the tires recommended by aircraft manufacturers, the increase in tire pressure will increase the stress of the rims if the tires with less width are used.
2. Since the rim rib stress caused by higher tire pressure, low safety factor, there is a possible condition of rib cracking in hard landing.
3. If there is an obligation to use tires with less width, the rib corners should be filled, and stress distribution should be provided to avoid the notch effect.

References:

1. A. B. Lagerweij, “Development and production of a new prototype tire and rim for remote controlled model racing cars,” University of Twente, 2023.
2. P. Kubiak *et al.*, “Research of damage to the rear wheel rim in a tipper-truck,” *Bull. Polish Acad. Sci. Tech. Sci.*, vol. 70, no. 3, 2022.
3. M. S. M. Shafiee and S. Saadon, “Conceptual Design of Out-of-Roundness Test Equipment for Aircraft Wheels,” *J. Aeronaut. Astronaut. Aviat.*, vol. 56, no. 1S, pp. 291–298, 2024.
4. J.-D. Wacker, D. Laveuve, C. C. Asins, and A. Büter, “Design of a composite nose wheel for commercial aircraft,” in *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1024, no. 1, p. 12018.
5. W. L. Lawton, “Static load contact pressure patterns under airplane tires,” *Highw. Res. Board Proc*, vol. 36, pp. 233–239, 1957.
6. M. Wesołowski, K. Blacha, and P. Pietruszewski Pawełand Iwanowski, “Analysis of the actual contact surface of selected aircraft tires with the airport pavement as a function of pressure and vertical load,” *Coatings*, vol. 10, no. 6, p. 591, 2020.
7. L. Solazzi, N. Danzi, and M. Cima, “Development of a FEM procedure for evaluating the pressure profile in the industrial wheel and fatigue strength analyses,” *J. Appl. Eng. Sci.*, vol. 22, no. 1, pp. 171–183, 2024.

UDC 629.7

Shkolnyi V., Bondarenko O.

CONTROL SYSTEM FOR AERODYNAMIC OSCILLATIONS OF UNMANNED AERIAL VEHICLE

Introduction. A common approach to improving aeroelasticity is to increase the wing stiffness and limit flight speed [1], but this can lead to a decrease in weight efficiency and limit the UAV's maneuverability. Recently, there has been research on the phenomenon of aeroelasticity [2, 3], and methods have been proposed to optimize designs to improve aeroelastic characteristics. Since this work involves multiple fields of knowledge, not all aspects can be fully covered in the current scientific and technical literature. There is proposed a method for creating a correction link to ensure the required dynamics of the aeroelastic model and verifies it using a proportional-integral controller.

Scientific and technical results. The aim of this work is to assess the effectiveness of a method for actively changing the geometric parameters of a UAV wing to influence its aeroelasticity. The method should be verified through semi-physical modeling using applied mathematical and design software packages. The input geometric and physical parameters for the mathematical model should be obtained during the UAV design phase using solid modeling and aerodynamic calculations for a specific design. The mathematical modeling was conducted based on a theoretical (binary) aeroelastic model using applied software packages like Matlab Simulink. As a result of the modeling, correction link coefficients in the form of a PID controller were selected to change the phase delay of the flutter according to a specific law, thereby increasing the critical flutter speed by a significant amount.

The effectiveness of actively changing the geometric parameters of the wing on its aeroelasticity will be analyzed based on the UAV VTOL "C-Flyer" (see Fig.1) which is equipped with standard flight control surfaces, including altitude control, ailerons and a rudder.

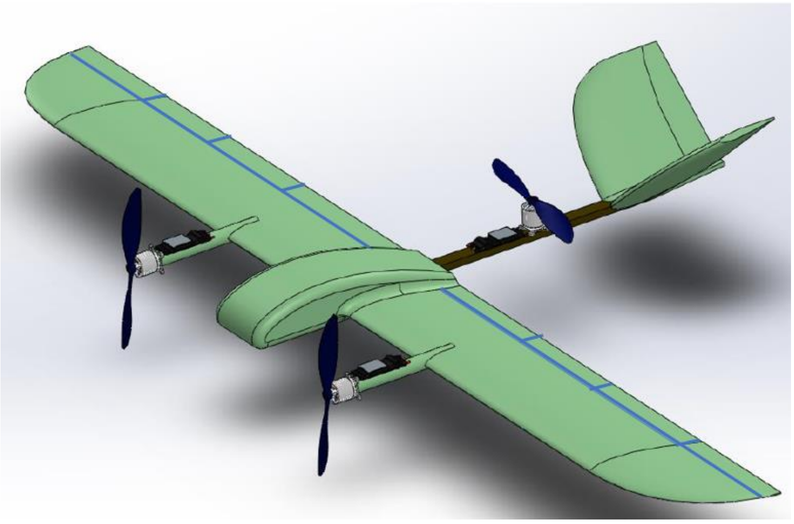


Figure 1 - UAV VTOL "C-Flyer"

Let's consider a binary aeroelastic model consisting of a homogeneous rigid rectangular wing with degrees of freedom for pitch angle θ and aileron deflection angle κ, which are represented as two springs (see Fig.2). The model includes a rigid control surface along the full span of the wing. The control surface has infinite stiffness at the attachment to the wing but can be rotated to any angle β. The inertial effects of the control surface are neglected. Therefore, the control surface does not participate in the main dynamics of the wing but acts simply as an excitation device.

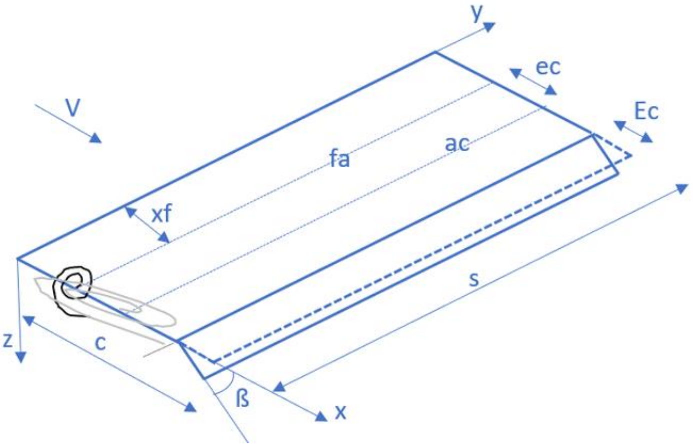


Figure 2 - Binary aeroelastic model with control surface

One of the simplest control system forms is the proportional-integral (PI) controller, which works by making the deflection angle of the control surface linearly proportional to the system's speed and displacement. The mathematical model of the wing takes into account wind gusts (see Fig.3).

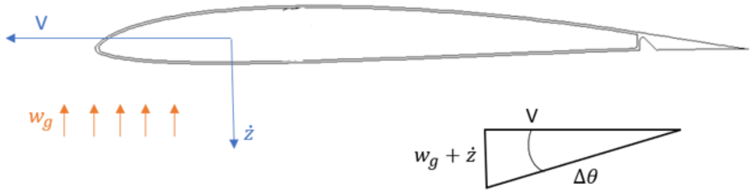


Figure 3- Effective angle of deflection due to vertical gust

To determine the response of the binary aeroelastic system under the influence of disturbances from the control surface as well as vertical wind gusts, a model has been created in the SIMULINK package (see Fig.4). Random turbulent disturbances are generated using the inverse Fourier transform of amplitude variations and random phases in the frequency domain.

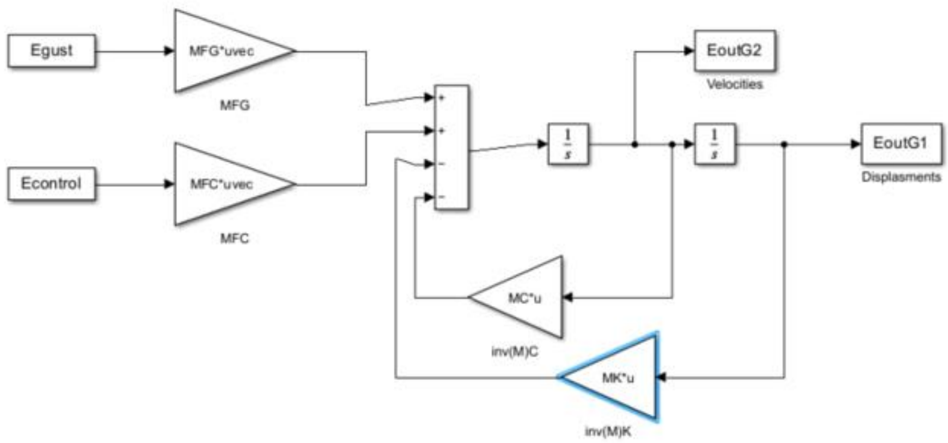


Figure 4- Block diagram of aeroelasticity control model

The modeling results confirm that by selecting the coefficients of the proportional-integral controller in equation for the control surfaces, it is possible to either reduce the twist angles during flutter by at least 30% or increase the flutter speed by the same 30% while maintaining the same oscillation amplitudes, compared to a standard wing without active control (see Fig.5).

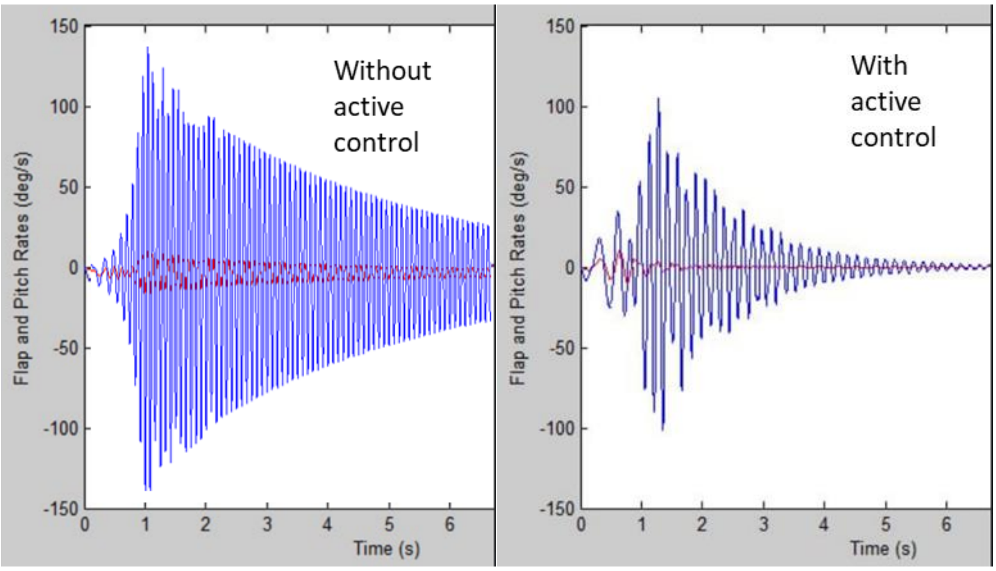


Figure 5- Wing response at flight speed of 50 m/s

Conclusion. The method of actively changing the geometric parameters of a UAV wing, using aileron deflections as an example, demonstrates the effectiveness of applying a control system to improve aeroelastic characteristics. This can significantly impact the design of aircraft with enhanced operational features, such as increased durability and higher short-term flight speeds. As part of the study, simulations were conducted in the SIMULINK environment to assess the effect of aileron deflections on the aeroelastic properties of the wings. The modeling confirmed the effectiveness of the active aeroelastic control method in increasing the flutter speed of UAVs by at least 30% using a simple proportional-integral control law. The study supports the feasibility of incorporating active control elements, such as ailerons, into wing designs to reduce deformations and improve overall aerodynamic performance.

References:

1. Possibilities of the Finite Element Method for Aeroelastic Analysis of a Light-Class Aircraft Wing // O.M. Bondarenko, M.U. Fedorenko. – Mechanics of Gyroscopic Systems. Scientific and Technical Journal. Kyiv: Igor Sikorsky Kyiv Polytechnic Institute – Issue 47. – 2024. – p. 110-112.
2. Krüger, W., Meddaikar, Y., Dillinger, J., Sodja, J., De Breuker, R. Application of Aeroelastic Tailoring for Load Alleviation on a Flying Demonstrator Wing. // mdpi.com – 2022. – Available at: https://www.mdpi.com/2226-4310/9/10/535
3. Successful Demonstration of Active Flutter // dlr.de – 2023. – Available at: https://www.dlr.de/en/latest/news/2023/03/scientists-tame-dreaded-aviation-phenomenon

UDC 621.396

Stefurak T., Arkhipov O.

QUASI-ZERO-STIFFNESS VIBRATION ISOLATION SYSTEM WITH A CONICAL DISK SPRING STIFFNESS CORRECTOR

Problem Statement. Almost all modern mechanisms encounter vibrations that affect their performance. Vibrations can lead to structural damage. Vibration and acoustic loads are responsible for 30–60% of system failures in space within the first day of mission [1]. This is due to significant unidirectional loads, primarily generated by the engine during launch, which can reach up to 20 G.

Statement of the main materials of the study. One of the effective methods for vibration protection is quasi-zero-stiffness (QZS) vibration isolation systems. QZS systems have the advantage of nonlinearity and can operate efficiently at very low frequencies, from 1–2 Hz [2].

QZS systems combine elastic elements with positive and negative stiffness. The positive element provides load-bearing properties, while the negative element corrects the system by reducing its overall stiffness. Stiffness correctors can include mechanical springs, pre-compressed beams, magnetic systems, or composite materials [2].

We consider a QZS system with a conical disk spring, axially loaded to provide an axial nonlinear restoring force. A linear compression spring is used as the load-bearing element. This system provides vibration protection in only one direction, while spatial vibrations can be mitigated by adding a second layer around the system [3] or by combining multiple such systems at different angles, such as in a Stewart platform, to achieve 3 or 6 degrees of freedom [4].

The system's stiffness must ensure a horizontal position of the corrector in equilibrium with the working load. The corrector should be preloaded so that stiffness decreases with any displacement from equilibrium. Stiffness and amplitude can be adjusted by connecting multiple disk springs in series or parallel.

At equilibrium, the corrector has practically zero stiffness, and further loading results in a sharp displacement with a jump phenomenon as the disk spring reverses its cone orientation. Parallel placement of correctors increases system stability [5]. The force response of such a QZS system will be nonlinear, with a near-zero response at small displacements.

When calculating QZS systems, the damping coefficient is crucial, as it defines the "softness" of the system and how quickly it dampens vibrations. Depending on this coefficient, nonlinearity, and vibration amplitude, the frequency response of the system can exhibit three types of solutions.

For a low damping coefficient, the frequency response has no real solutions, causing continuous amplitude growth. With increased damping, the system may have two real solutions, leading to a jump phenomenon [5] and unstable zones where the amplitude changes in a jump-like manner. In this case, the frequency response graph shows a peak with a rightward curve and hysteresis when the frequency changes in different directions [6].

With further damping increase, the system behaves linearly, without jumps or peaks in the frequency response curve.

Conclusions. QZS systems can provide effective protection at low frequencies and reduce vibration transmission. Conical disk springs allow for near-zero stiffness at equilibrium. The parameters of such systems can be adjusted to enhance stability.

Depending on the damping coefficient, QZS systems can exhibit both instability and predictable behavior, making them promising for vibration isolation with proper parameter tuning.

References

1. Timmins, A.R. and Heuser, R.E., 1971. *A Study of First-Day Space Malfunctions.* NASA TND-6474, Goddard Space Flight Center.
2. Ma, Z., Zhou, R. and Yang, Q., 2022. *Recent Advances in Quasi-Zero Stiffness Vibration Isolation Systems: An Overview and Future Possibilities. Machines*, 10, p.813.
3. Arkhypov, O., Bakun, V., Sukhov, V., Kozei, Y. and Marynoshenko, O., 2020. *Vibro protective systems of quasi zero rigidity.* In: *Theoretical aspects of modern engineering: collective monograph*, International Science Group, Boston.
4. Niu, F., Meng, L. and Wu, W., 2014. *A Six Degrees-of-Freedom Vibration Isolation Platform Supported by a Hexapod of Quasi-Zero-Stiffness Struts. Journal of Vibroengineering*, 16(4).
5. Carrella, A., Brennan, M.J. and Waters, T.P., 2007. *Static analysis of a passive vibration isolator with quasi-zero-stiffness characteristic. Journal of Sound and Vibration*, 301(3–5).
6. Abolfathi, A., 2023. *Can a nonlinear quasi-zero-stiffness spring improve the ride quality of a vehicle? Vehicle System Dynamics.*

UDC 629.7

Tomko D.

EXPERIMENTAL DEFINITION DEPENDENCE OF MECHANICAL CHARACTERISTICS COMPOSITE PANELS FROM ORIENTATION FIBERS

Introduction. One of the main directions of the development of the aviation and space rocket industry of Ukraine is the modernization of existing and the creation of new models of rocket and space technology in international cooperation. The implementation of this direction allows us to reduce the budget burden, get rid of dependence on traditional partners who have become our enemies, combine new technologies with the aim of creating rocket and space technology with higher characteristics, and receive financial support at the expense of commercial launch services.

The goal of the research is the development of promising materials that combine high reliability with low cost and mass, which will provide high reliability indicators.

Scientific and technical results. To study the properties, a twill weave carbon fabric was chosen, which provides a good aesthetic appearance, which is desirable for modern composite parts, and has high formability and greater strength than plain weave. The graphite fibers in this fabric contain up to 95% carbon and provide the highest tensile strength. The fabric used for the research has higher strength and stiffness-to-weight ratios than any other commonly available reinforcing material. Pro-set LAM 125 epoxy resin was used to maximize the properties of the fiber.

For research, 2 slabs of research material measuring 1100 mm x 1200 mm were made - the first 1 mm thick, the second in the form of a 12 mm thick "sandwich" panel (1 mm thick carbon plastic + 10 mm Aerex filler + 1 mm thick carbon plastic). The research material was produced by the method of vacuum infusion (Fig. 1).

Figure 1 – General view of the research material was produced by the method of vacuum infusion

Samples were cut using a milling machine with software control, which ensured compliance with the required accuracy. Samples were cut from three directions: along the fibers, across the fibers, and at an angle of 45° to the longitudinal direction.

The tests were carried out on samples manufactured in accordance with ISO 527-1 (Fig. 2).

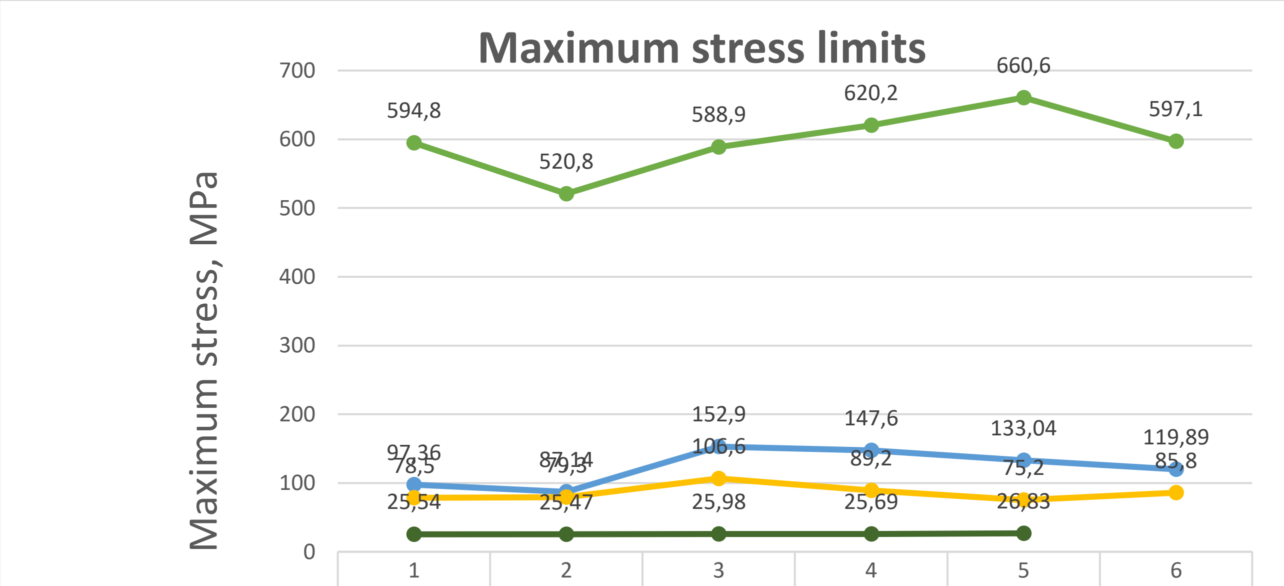
Figure 2 – General view of the samples

Samples were also tested to determine the modulus of elasticity and Poisson's ratio.

Single rectangular P1 tensors were used to determine the specified characteristics of mechanical properties. Tensor resistors were placed at an angle of 90° relative to each other.

Figure 3 – General appearance of samples before testing.

Test results of samples of composite materials with determination of modulus of elasticity and Poisson's ratio and maximum load/stress (Fig. 4).



	1	2	3	4	5	6
tape (along the fibers)	594,8	520,8	588,9	620,2	660,6	597,1
tape (45°)	97,36	87,14	152,9	147,6	133,04	119,89
tape (across the fibers)	78,5	79,3	106,6	89,2	75,2	85,8
panel	25,54	25,47	25,98	25,69	26,83	

Figure 4 - Test results of samples of composite materials

Conclusion. The obtained mechanical characteristics of the material in the composition of the three-layer composite panel with Aerex filler do not correspond to the material characteristics obtained from the results of tests of the monolithic layer of the material.

The possibility of using the mechanical characteristics of the material on samples according to ISO 527-1 to assess the stress-strain state of the outer layers of the three-layer panel has been experimentally confirmed.

References:

1. Kucher, M. and Zarazovskii, M. (2009), "Otsinca mitsnosti sharuvatych plastykiv iz vrachuvannjam degradatsii mechanichnyh haracterystyk v protsesi deformuvannja", National Technical University of Ukraine "Kyiv Polytechnic Institute". Series of mechanical engineering.Vestnik NTUU «KPI». Serija Mashynostroenie, vol. 57, pp. 174 – 179.

2. Zarazovskii, M. (2009), Deformuvannja i mitsnist sharuvatyh vugleplastykiv pry kimnatni i kriogennuh temperaturah: dissertation of PhD in Technical Sciences: 01.02.04, Kiev, Ukraine.

3. Soden, P.D., Hinton, M.J. and Kaddour, A.S. (1998), "Lamina properties, lay-up configurations and loading conditions for a range of fiber-reinforced composite laminates", Composites Science and Technology, vol. 58, no. 7, pp. 1011 – 1022. https://doi.org/10.1016/S0266-3538(98)00078-5

4. Rubashevskyi, V., Zarazovskii, M. and Shukyev, S. (2017), "Analysis of methods for determination of the constants of elasticity unidirectional layer composite materials", Mechanics and Advanced Technologies, vol. 80. no. 2, pp. 107 – 112. http://dx.doi.org/10.20535/2521-1943.2017.80.109634

5. Horoshun, L. (1993), Staticheskaja machanica i efectivnye svoystva materialov [Статистическая механика и эффективные свойства материалов], Mechanica compositov, in Guzja A.N. (ed.), Nauk. Dumka, Kiev, Ukraine.

6. Soden, P.D., Hinton, M.J. and Kaddour, A.S. (2002), "Biaxial test results for strength and deformation of a range of E-glass and carbon fibre reinforced composite laminates: failure exercise benchmark data", Composites Science and Technology, vol. 62, no. 12, pp. 1489 – 1514.

UDC 629.735.33

Yevdokymov N. Larkov S.

CURRENT STATUS OF SMALL SATELLITES FOR EARTH REMOTE SENSING WITH SAR TECHNOLOGY

Introduction. In recent years, interest in small satellites for Earth remote sensing (ERS) using synthetic aperture radar (SAR) has grown significantly. This technology enables the acquisition of high-resolution images regardless of weather conditions or time of day over the observed area, which is extremely valuable for monitoring large regions, responding rapidly to natural disasters, and other important tasks where traditional optical sensors are less effective.

Scientific and Technological Outcomes. The primary advantage of SAR satellites is their ability to operate in adverse weather conditions, such as cloud cover, fog, and smoke, as well as nighttime operations. This makes these satellites effective in emergency situations where rapid data acquisition is crucial. For example, SAR satellites from the Finnish company ICEYE can achieve a resolution of up to 1 meter, allowing detailed monitoring of the Earth’s surface and scalable zooming as needed. The satellites from this company are equipped with X-band transmitters (9.65 GHz), active phased array antennas, and electronically controlled beams. The inherent mechanical maneuverability of these small satellites and their electronic control allow for rapid and precise targeting of radar pulses on the ground. The satellites can also capture images from the right or left side of the satellite’s trajectory[1]. The satellite operates in VV polarization (Vertical Transmit, Vertical Receive), where the sensor transmits a vertical signal and receives a vertical signal. The VV combination is commonly used for monitoring vertical structures, such as forests or urban buildings. All of the company’s satellites are in sun-synchronous orbits at altitudes of 560-580 km and perform 15 revolutions per day. Each satellite can slowly adjust its orbit over its operational life. Adjustments are typically made within the orbital plane by raising or lowering the satellite’s altitude.

Another pioneering company, Capella Space, uses satellites built with SAR technology to track and capture small-scale changes on the Earth’s surface under any weather conditions and at any time of day. For instance, they monitor ports and open sections of pipelines, agricultural fields, and open seas. The company's satellites have a resolution of 0.5 meters and are equipped with an X-band transmitter (9.4-9.9 GHz). They operate in inclined and sun-synchronous orbits at altitudes of 525-550 km[2]. Capella also provides precise classification of ships based on high-resolution SAR images. Clients can automate detection and classification in areas such as ports, shipping lanes, and exclusive economic zones to gain valuable insights[3].

Both companies have combined their satellites into constellations, which allows them to increase surface coverage for Earth observation and ensure nearly continuous access to radar images across various regions of the world.

ICEYE and Capella Space, focus on miniaturizing and optimizing SAR technology to reduce the size, weight, and cost of their satellites. ICEYE is oriented towards more affordable and versatile systems suitable for a broad range of commercial applications. Capella Space, on the other hand, focuses on maximum image detail and high update frequency, making its constellation valuable for government clients and tasks where detail and accuracy are critically important.

Conclusions. The use of small satellites with SAR radar has significant potential for enhancing global monitoring efficiency and acquiring high-quality data regardless of weather conditions. Further advancements in miniaturization and the development of satellite constellations that combine SAR and optical systems will enable more accurate and timely data for various applications, from agriculture to national security.

References:

1. ICEYE, 2024. Product Guide: Fleet. [online] Available at: https://sar.iceye.com/5.2.0/productguide/fleet/ [Accessed 7 Nov. 2024].
2. ICEYE, 2024. Product Guide: Fleet. [online] Available at: https://sar.iceye.com/5.2.0/productguide/fleet/ [Accessed 7 Nov. 2024].
3. Capella Space, 2024. Earth Observation Data. [online] Available at: https://www.capellaspace.com/earth-observation/data [Accessed 7 Nov. 2024].

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CHALLENGES DURING GROUND VIBRATION TESTING OF FLEXIBLE LIGHT AIRCRAFT

Statement of the problem. Ground vibration tests (GVT) are an integral part of the design and certification of aircraft. The results are used to research the aircraft's natural modes and to validate its mathematical model. However, when it comes to flexible lightweight research objects, GVT equipment can change the eigenmodes of the structure. This is because they are made of lightweight materials with high flexibility. Traditional GVT methods can provide misleading results if the results are used without taking into account the weight and additional stiffness created by the equipment.

Improvements in test methodology or result processing are needed to address this issue.

Statement of the main materials of the study. The challenges that arise during GVT include the following:

1. The closeness of low natural frequencies to the frequencies of the suspension system. Experimental studies show that the natural frequencies of flexible light aircraft are very low (less than 1 Hz) [1]. This feature creates difficulties during GVT, as these frequencies are close to the frequencies of the suspension system. This leads to a coupling between the aircraft dynamics and the suspension system. This interaction can significantly affect the accuracy of the data obtained.

2. Influence of sensor weight. For more rigid structures, the weight of the accelerometers used for the study is usually ignored because its influence is minor. But for lightweight structures, this weight can significantly change the modal characteristics of a flexible structure. Therefore, it becomes important to take into account the weight of the sensors in mathematical models to ensure an accurate representation of the model and the results that follow.

3. Geometric nonlinearities and dependence on the deformed shape. If we compare lightweight flexible aircraft with conventional ones, the first ones will have significant deformations under the influence of aerodynamic, inertial, or controlled loads. These deformations are large enough to cause significant changes in the shape of the aircraft, which changes its stiffness and mass distribution in real time. These changes lead to nonlinear dynamic behavior, which complicates modelling and analysis.

4. Correct excitation and placement of sensors. For flexible aircraft, determining the optimal location and type of excitation (shaker, impact hammer) is important to excite the desired modes while minimizing unwanted responses. Equally important is the correct sensor placement strategy to accurately measure the dynamic response of the aircraft. Their number and location have an impact on the accuracy of model mode identification [2].

Conclusion. GVT of lightweight flexible aircraft faces numerous complications due to the unique properties of this design. Due to their low weight and high structural flexibility, these types of aircraft are very sensitive to the equipment used for testing. Therefore, when testing these structures, it is necessary to take into account the influence of the aircraft suspension system and the weight of the sensors. Geometric nonlinearities make it difficult to precisely model and predict the behavior of the aircraft. In addition, proper sensor placement and selection of the correct excitation method play a significant role in obtaining reliable results.

References:

1. Sharqi, B. Cesnik, C.E.. (2020). Ground Vibration Testing on Very Flexible Aircraft. AIAA 2020-1902: AIAA Scitech 2020 Forum, January 2020. https://doi.org/10.2514/6.2020-1902 (Accessed 01.11.2024).

2. Gupta, A., Seiler, P., Danowsky, B.. (2016). Ground Vibration Tests on a Flexible Flying Wing Aircraft. *AIAA* 2016-1753: AIAA Atmospheric Flight Mechanics Conference. January 2016. https://doi.org/10.2514/6.2016-1753 (Accessed 01.11.2024).