MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL TECHNICAL UNIVERSITY OF UKRAINE “IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE”

INSTITUTE OF AEROSPACE TECHNOLOGIES

Intelligence. Integration. Reliability

XIV international students and young scientists conference 7th December 2021

Kyiv
NTUU "Igor Sikorsky Kyiv Polytechnic Institute"
2021

CONTENTS

UDC 629.3

Ajewski J., Bartczak M., Guty B.

ORION – VEHICLE WITH EXTREMELY LOW FUEL CONSUMPTION

Introduction. We are students of the Students Association for Vehicle Aerodynamics at the MEiL faculty on WUT. The main goal of our Orion project was to create an ecological and reliable vehicle that could take part in the international Shell Eco-marathon competition in the urban concept category. Vehicle must meet all the requirements of road traffic. Orion was designed by students of the association using CAE (computer-aided engineering) systems. The aerodynamics of the vehicle was optimised thanks to the CFD (computational fluid dynamics) software.

Scientific and technical results.

1. Self-supporting composite structure. A monocoque made of carbon-epoxy composite is the central part of the Orion vehicle. It is both a chassis and a body of the car. The rest of the vehicle's systems are attached to it: suspension, steering, drivetrain and electronic systems. Thanks to the optimisation of the carbon composite layers, it was possible to achieve high strength and stiffness of the structure and reduce the weight (about 120 kg for a complete vehicle) compared to the aluminium structure. The self-supporting structure is a safety cage for the driver in case of hitting an obstacle. The special longitudinal arrangement of carbon fibre panels with a foam spacer at the front of the vehicle is a crush zone that stores energy thanks to the composite delamination mechanism.

The regulations of the Urban-Concept category require an upright position of the driver and the road and the vehicle's surroundings to be visible. The vehicle can be accessed through the spectacularly floating doors located on both sides of the car, and their hinges and fasteners are made of carbon fibre.

Composite construction is exposed to vibrations and high loads that it must transfer from other elements. In order to provide a greater load-bearing capacity of the composite at the points of force application, reinforced nodes were created by placing aluminium elements in the composite spacer. The firewall that separates the driver from the engine compartment, which also has to bear loads from the rear suspension and withstand high engine temperatures, has been reinforced. It has a specially designed and optimised aluminium plate.

The shape of the monocoque is also optimised in terms of aerodynamics. The primary assumption was a low aerodynamic drag. It has also been designed to generate downforce to improve contact between tires and the road. That was achieved by smooth surfaces that made the car's body look like a drop of water. A profiled floor with a diffuser generates pressure without increasing resistance. The ANSYS CFD software was used to optimise the shape.

2. Engine and drive train. The engine used in Orion is the SANYANG Mio - originally a scooter engine with a capacity of 50 cubic centimetres and a nominal power of 3.8 horsepower. Due to the specific mode of operation in which the engine works during the Shell Eco-Marathon competition, several modernisations were

applied to compete for the highest places in the category of cars powered by an internal combustion engine:

- some components in the engine have been replaced with their lighter counterparts: piston, connecting rod and a crankcase with a shorter cylinder;
- the compression ratio has been raised for more power and efficiency;
- a unique intake system with an electronic throttle was created to ensure a constant flow of air into the engine using a dynamic boost;
- an exhaust system was made with a place for a lambda probe;
- the vehicle is equipped with indirect fuel injection powered by compressed air.

The engine is controlled by the Ecumaster EMU sports controller, which allows many engine's operating parameters (the amount of air supplied, the throttle opening angle, ignition time).

In order to reduce weight and size, the gearbox and the clutch have also been removed. Power is transferred to the wheel through a clutch with a synchroniser and a 3-speed planetary gear in order to operate in the optimal range of revolutions all time.

Innovative dog-clutch allowing to reduce mechanical losses compared to the previously used centrifugal clutch. There is also better control over the engagement process.

3. Suspension, steering and braking system. Steering knuckles are connected to the steering gear employing rods ending on both sides with ball joints. As a result, Orion achieved a precise, lightweight and reliable transmission of the steering wheel rotation to the rotation of wheels. The steering wheel is equipped with a quick-release system, which allows the driver to sit in the proper position and quickly leave the vehicle in case of an emergency.

Conclusion. The Orion vehicle is a look to the future of the automotive industry, is a model of searching for ecological innovation. The project refers to the current air pollution problem and broadens the awareness of this problem among future constructors. Working on the project, we create a friendly environment for the ideas exchange, and we gain various skills in CAE, a vivid example of which is a running car competing in competitions.

UDC 62-1/-9

Bakun V., Marynosenko O.

INTRODUCTION OF ADDITIVE TECHNOLOGIES IN STAND FIRE TESTS OF ROCKET ENGINES

(on the example of a gas-dynamic tube for low-thrust rocket engines)

Introduction. Rocket engine stand fire tests are not an integral part of their production. During vacuum stand tests, the gas-dynamic tube notices the operation of the stand as a whole and requires correct calculation. This requirement must be met for both high-thrust and low-thrust engines [1]. Traditionally, the gas-dynamic tube consists of a confuser, diffuser and a cylindrical part. In addition, the gas-dynamic tube must be cooled to prevent overheating [2].

The construction of a gas-dynamic tube is not very difficult to design, but difficulties arise during its production. Non-standard taper angles for the confuser and diffuser, such as 7 degrees and 45 minutes, could be used during calculating the performance of the gas tube [3]. This causes difficulties during the production of these elements, as well as the final assembly of the gas-dynamic tube, especially during welding of structural elements. The production of a gas-dynamic tube requires a large number of different types of equipment, as well as human resources [4].

Scientific and technical results. The introduction of additive technologies in the design of gas tube lines facilitates the method of its production and allows more accurate adherence to the parameters determined during the calculation of performance. Figure 1 shows a gas-dynamic tube for low-thrust engines, where the confuser and diffuser are designed by using 3D printing. Also, the ability to use 3D printing allows you to use channels for cooling, as shown in Figure 1 (section A-A). This makes it possible to use the coolant more efficiently at a lower cost.

This experimental design of the gas-dynamic tube was designed and manufactured at the company "Flight Control" LLC.

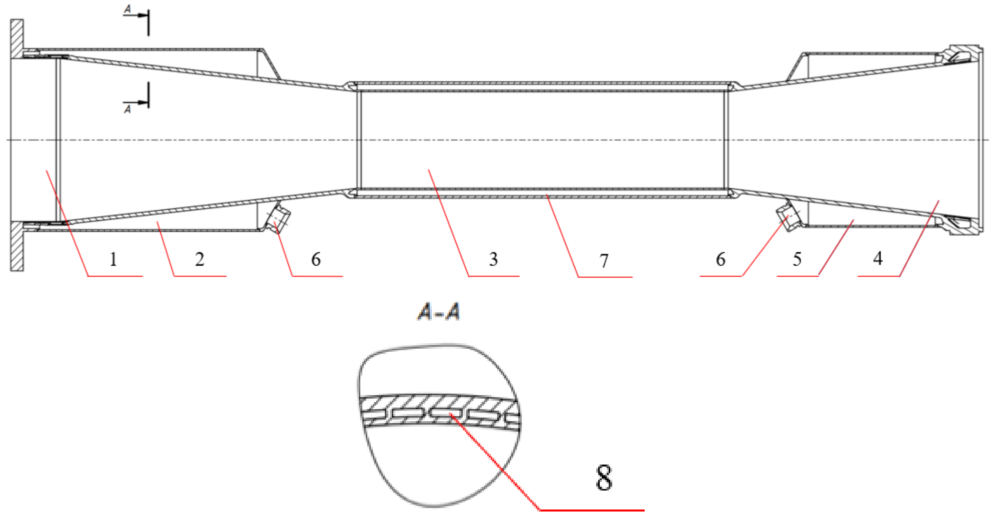


Fig. 1. Gas-dynamic tube. 1 – confuser; 2 – confuser collector; 3 – cylindrical part; 4 – diffuser; 5 – diffuser collector; 6 – fittings for coolant supply; 7 – cooling circuit; 8 - channels for cooling.

Conclusion. Overall, the main changes in the introduction of additive technologies in the elements of the stands in the fire tests onset:

- Easier manufacturing in accordance with the traditional methods of manufacturing;
- Economic and resource transfers;
- Preservation of short cooling of internal walls of gas-dynamic tubes with less spending of cooling liquid in the case of traditional gas-dynamic tubes designs.

References:

1. Pempie P., Vernin H. Liquid Rocket Engine Test Plan Comparison. 37th Joint Propulsion Conference and Exhibit, 2001, p. 3256.

2. Shankar G.P. FE Modelling and Analysis of: Carbon-carbon Nozzle Exit Cone for Use in CE-20 Cryogenic Engine and Metal-composite Interface Joints Subjected to Thermo-structural Loads. Department of Aerospace Engineering Indian Institute of Space Science and Technology, 2016.

3. Manikanda Kumaran R., Sundararajan T. Performance Evaluation of SecondThroat Diffuser for High-Altitude-Test Facility. Journal of Propulsion and Power, 2010, vol. 26 (2), pp. 248–258.

4. Sung H.G., Yeom H.W., Yoon S., Kim S.J., Kim J. Investigation of Rocket Exhaust Diffusers for Altitude Simulation. Journal of Propulsion and Power, 2010, vol. 26 (2), pp. 240–247.

UDC 629.05

Chernenko S., Burnashev V.

CONTROL SYSTEM FOR UNMANNED AIRPLANE AUTOMATIC LANDING

Introduction. Automated landing systems are designed to ensure the landing of UAVs under adverse weather conditions, at any time of the day, without human intervention. The success of this important and unsafe task depends on the efficiency of real-time aviation.

The aim of the work is to develop a system that can help to model control systems, algorithms, stabilization etc. Described non-linear model of aircraft in a longitudinal way. Found the balancing position of control surfaces for small unmanned aircraft vehicles and carried out linearization around fixed points. For control under a non-linear model the Linear Quadratic Regulator (LQR) that minimizes special cost function. A flight controller on a 4-layer printed circuit board was developed using a modern microcontroller STM32F4 and some other electronic devices. Developed model in MATLAB Simulink that can provide simulation in semi-nature way. Described control algorithm embedded in the flight-controller, that is already connected to the program. In a PC modeled environment and nonlinear model of original aircraft, that communicates with the device in real time.

The software part of the device is based on the Free-RTOS real-time operating system and can be easily modified in future operation. This provides the flexibility of the embedded software solution and the controllability of the flight task, operation algorithm, etc.

Scientific and technical results. Today the problem of automatic landing is not new, but still remains one of the most dangerous maneuvers in comparison with other phases of operation. Mainly it is due to:

1) crew error, which has a more pronounced effect on pilotless systems, under conditions of delayed reaction to manual control, poor positioning in trivial space, lack of overload, etc.

2) Technological inconsistency and through large abnormalities of inertial guidance systems. To solve the problem of obtaining reliable information, data integration schemes are used. This leads to complication of the management system and reduction of its economic efficiency.

3) The use of radio-electronic warfare systems, which leads to degradation of almost all additional systems of data complexing of the internal navigation system.

Today it is very important to take into account all stages of development of modern aircraft. The development of the control system is still very expensive, despite the rapid development of technology and control methods.

A flight controller is proposed, which will have a software and hardware module. This module is used to test algorithms for synthesis of laws of control of the airframe at full-scale modeling and under real operating conditions on a nonlinear model of the airframe with additional consideration of internal turbulence.

Relevance. Interest in the topic is caused by widespread use of similar solutions. Such systems can not only minimize the impact of the aircraft control system on its total cost but also ensure safety of older aircraft of the last century in which such systems are absent altogether. This can be a control system when the pilot is physically unable to operate the aircraft (e.g., lost consciousness), It can also be a system of flight over unnecessary or hazardous air zones (thunderstorm, strong violent wind, flying the radius of action of an air defence), patrolling state border, as well as automatic landing of the aircraft.

Conclusions. Computing capacities and hardware are developing rapidly. This is primarily due to the fact that a very large number of calculators are being produced. This increase in the production of processors should lead to an increase in their quality and a reduction in the cost of the final product. This has a positive effect on automated control systems that use them.

The systems implemented using modern methods and modern equipment will enable the use of cheaper, qualitatively not worse or even better automatic control systems for the use of the aircraft.

Practical value is very wide, starting from synthesis of new control laws and finishing with real, final designs based on the typical one.

UDC 629.014-519:656.022.31

Dmytruk B., Sereda T.

FLYING TAXIS

Introduction. Nowadays, each of us values our time more and more and thinks about the external environment. To do this, we replace our cars with electric ones that have autopilot, buy products with artificial intelligence and from less noise occurs. To save time, more and more people are buying cars, and with the increase in cars, the problem of traffic jams is growing. For many, the road takes a lot of time and effort every day. An excellent solution to this problem will be the use of an unmanned aerial vehicle as a taxi.

Scientific and technical results. Electric air taxis can be of different shapes and sizes. Electric motors replace jet engines, vertical takeoff and landing aircraft designed to avoid the need for long runways, with rotatable wings and, in some cases [1], propellers instead of propellers. Only a few companies produce vehicles that actually look like winged cars.

Fig. 1. Lilium Jet.

Many companies work on development of such a product. For example, such big brands as Toyota, Uber, Hyundai, Airbus and Boeing [1] promise to take passengers in the sky in flying taxis, the dream is getting closer to reality.

The advantage is that unmanned taxis do not need breaks and time to sleep, do not need to take an alcohol test - because such cars do not need drivers who can get tired and even quarrel with passengers. Such a trip will be fast and without traffic jams.

An example of such a taxi is Voyager X2. This is a fifth-generation "flying car" from Xpeng Huitian, a subsidiary of Xpeng (Xiaopeng) Motors. The X2 is the first of the Xpeng flying cars with a closed cabin required for high-altitude flights. Its fuselage is made of carbon fiber and weighs about 266 m along with the battery. The current model can carry two passengers under a maximum load of about 135 meters.

According to XPeng, Voyager X2 has an autopilot function that can perform automatic flight according to a predetermined altitude [2], speed and flight time on the planned route. Currently, the X2 can operate for up to 2100 s and is designed for flights at altitudes of less than 1000 m. At maximum speed this car can be seen at a speed of about 36.1 m / s.

Air taxis are a future modern public transport, which is being tested, but in the near future it is planned to be used to transport passengers. For example, Korea and Japan plan to start commercial use of summer taxis in 2025 [3].

Conclusion. Air taxi is a kind of general concept of taxi, which is often perceived as the transportation of passengers by cars or small water taxi. At the same time, air taxis are a more expensive mode of transport.

Unmanned flying taxis have many more advantages than conventional ones, so their implementation in our life will be in demand.

References:

1. https://www.cnbc.com/2020/03/06/the-flying-taxi-market-is-ready-to-change-worldwide-travel.html
2. https://electrek.co/2021/08/30/xpeng-says-voyager-x2-has-begun-flying-in-extreme-environments-and-high-altitudes/
3. https://www.techtimes.com/articles/267070/20211024/japan-airlines-plans-launch-flying-car-business.html

UDC 681.518.3

Gajek S., Tokarz D., Kopyt A.

MIXED REALITY AND ASSESSMENT AUTOMATION IN NEW APPROACH FOR UAV TRAININGS

Introduction. Both public and private markets show demand for safe and reliable automated unmanned aircraft systems. This statement may be backed by recent legal changes performed by European Commission, who however still emphasises the importance of a human responsibly commanding a drone. Referring to those recommendations, a more modern approach to UAV pilot's training should be developed. In the proposed solution these expectations are met by mixed reality (MR) techniques coupled with automated flight assessment methods.

Scientific and technical results. The designed simulator enables a course based on the concept of Multi-stage Approach®™ proffered by Antoni Kopyt, Ph.D. It utilises advantages brought by Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) by bringing means of interaction with artificially generated obstacles both in simulated and real environment. This aids trainee's fluent transition between training conditions and professional services. The Simulation Station is based on open flight controller software (such as ArduPilot or PX4) which is easily integrated with real RC controller. Such a solution provides ways of software testing in the SITL (Software-in-the-loop) approach or device testing in a HITL (Hardware-in-the-loop) approach by replacing a flight controller simulated on a PC with a real unit. Additionally, a separate Flight Assessment Module extended with Instructor's Panel are provided in order to perform both automated and manual flight performance grading.

The main objectives of this project are building a custom flight environment, providing a tool for creating uncharacteristic mission scenarios and aiding instructors with automatic flight analysis module, as well as the pilots themselves by giving them insight into log of their flight performance. In order to let the pilot practice in harsh and often unrepeatable scenarios, missions could be set up or live-triggered via specifically assembled Instructor's Panel interface. Data gathered during the activity is subjected to thorough dissection by a set of algorithms, resulting in breakdown of subject's performance in time, as well as its overall grading. The results may be directed to the instructor and pilot with an automatically generated post-flight report. Such a document provides them with an overview on pilot's progress and helps with preparing the optimal guidance during the rest of the course.

Conclusion. The report concludes with summary of project development and plans of advancements, that are to be achieved in the near future. It also provides a research into utilisation of Mixed Reality techniques for Unmanned Aircraft Systems.

UDC 629.7. 015.4 : 533.69.048.05

Hevko B., Bondar Ju.

DYNAMIC RESPONSE OF AN ELASTIC AIRCRAFT

Introduction. In computing the dynamic response of an airplane in flight, it is often assumed that the structure is perfectly rigid. On the basis of this assumption, externally applied forces, such as air or ground loads, are put into equilibrium with aerodynamic and inertial forces which arise as a result of translational and rotational motion of the airplane as a rigid body. This leads to certain errors. Deformation of the structure may induce additional aerodynamic forces which affect the over-all response of the airplane. Moreover, if the dynamic response is the direct result of rapidly applied external forces, structural vibrations are induced as well. They have a significant effect upon the internal stress distribution in the structure, and a somewhat lesser influence on the over-all response of the airplane [1]. The consequence of vibrations can be both a decrease of operational life and dangerous damage due to resonance. To do this, it is necessary to find out the circumstances under which the resonance occurs, and try to avoid the appropriate operating conditions. Ground Vibration Test (GVT) is one of the most important test procedures in aircraft certification. The distribution of stiffness, natural frequencies, oscillation shapes and structural damping of each aircraft component, which are necessary for flutter analysis and dynamic load analysis, are determined with the help of GVT [2]. However, since the GVT of the aircraft can be carried out only after its manufacture, so far the nature of the dynamic response of the aircraft can be determined only analytically.

The aim of this work is determining the influence of dynamic effects that occur during the operation of an aircraft on the magnitude and distribution of loads and overloads on the wing of an elastic aircraft.

A regional transport aircraft of the AN-178 type with a payload of 5000 kg and of 2650 kg of fuel is considered. The structure of the aircraft is modeled using elastic-beam schematization. 14 beams were used to describe the symmetrical structure of the aircraft (only the starboard was specified). The payload is modelled by means of concentrated masses which are evenly distributed along the cargo floor of the fuselage. The construction of computational models and modal analysis of the aircraft structure were carried out using the IMAD software package. The panel method of dipole lattice and constant pressures (DLM/CPM) was used to determine aerodynamic forces and moments.

Under conventional conditions, it is sufficient to consider shapes of natural oscillations of the aircraft structure up to a frequency of 30-40 Hz [3], but there are cases when it is necessary to take into account a much higher frequency. This cases is an engine imbalance. When the fan blade is detached, the speed of the fan rotor at the maximum cruising mode of the engine is 5800 rpm (96.7 Hz). In this case, oscillatory movements occur, which can cause resonance. Therefore, it is necessary to consider the frequencies of shapes that are close to the speed of the fan rotor. To do this, the study considered 52 symmetric (up to 114 Hz) and 65 antisymmetric (up to 112 Hz) shapes of natural oscillations of the aircraft structure.

Scientific and technical results. The loads and overloads that occur on the wing of the aircraft during horizontal flight, engine imbalance caused by the separation of the fan blade (in autorotation mode and maximum cruising mode) and flight in turbulent air (discrete gust and continuous turbulence) are considered. Loads calculation were performed for horizontal flight conditions at an altitude of H=9000 m with a speed of V_c=540 km/h. The highest values of bending moments M_x and shear force Q_y are obtained at the action of continuous turbulence, torque M_z – at the action of a discrete gust (at the end zone of the wing) and at continuous turbulence – at the root. Significant values of lateral overload n_z in the center of mass of the engine pylon obtained in the conditions of engine imbalance, indicate a coincidence of fan speeds and the frequency of natural oscillations of the aircraft structure (lateral oscillations of the pylon). If we exclude this oscillation shape from the calculation (which is actually unacceptable), the values of lateral overload will decrease three times, with a slight decrease of the values of all other force factors. This indicates that this oscillation shape is essential for determining the dynamic response of the aircraft to external disturbances.

Conclusion. The obtained results showed that: the greatest overloads on the wing occur in conditions of sustained engine imbalance, but the values of the loads are much lower than the loads effecting at the flight in turbulent air conditions. It is shown that the determination of the dynamic response of the aircraft at the flight requires the solution of aeroelasticity problems to ensure the required structural strength. There is also a need for GVT for a detailed study of the impact of engine imbalance.

References:

1. Bisplinghoff R. L. Aeroelasticy / R. L. Bisplinghoff, H. Ashley, R. L. Halfman. – Mineola, New York: Dover publications, Inc., 1996.
2. Santhosh K. N. Finite Element Analysis and Vibration Testing of a Simple Replicate Beam-Type Aircraft Wing with and without Secondary Structure Attached / K. N. Santhosh, Y. Yihun, M. L. Hamid. // Int J Aeronautics Aerospace Res. – 2015. – №2(3). – C. 27–38.
3. Wright J. R. Introduction to aircraft aeroelasticity and loads / J. R. Wright, J. E. Cooper. – Chichester: John Wiley & Sons, 2008.

UDC 624.042.68

Hoholieva D., Bondarenko O., Lymanskyi I.

INFLUENCE OF CUTS ON THE STRESS-STRAIN OF THIN-WALLED STRUCTURAL ELEMENTS

Introduction. The use of light steel thin-walled structures made of bent profiles in industrial and civil construction is constantly growing and serves as an impetus for the development of the entire construction industry, including the development, manufacture and installation of structures using thin-walled bent profiles.

Scientific and technical results. For a more detailed study of the effect of cross-sectional deplanation of thin-sheet plates in the presence or absence of notches on their stress-strain state (VAT), the calculation was performed by numerical ITU modeling of static load of thin-sheet samples (plates) with different stress concentrators simulating structural notches or operational defects of structural elements, present or occurring in the casing of the fuselage of transport aircraft using COMSOL software, the experimental method on the test machine UVM-40-2 and the analytical method (according to the methods of Garden and Kirsch) [1].

The study was conducted to model the static load of thin-plate plates of two types: solid and a plate with a small central hole (Ø, 4 mm).

Based on the obtained results and their comparison, conclusions are made about the peculiarities of the study of the influence of incisions on the VAT of thin-sheet plates by different methods:

- in the presence of a hole - the maximum voltage σ_max will be greater than for a solid plate;
- the presence of a hole in the plate causes a redistribution of stresses, and near the hole there are significant additional stresses at a distance of several diameters;
- the results of calculations by numerical methods actually coincide with the results calculated by the analytical method, however, the values of stresses obtained by the experimental method differ significantly for the minimum voltage value σ_min, although almost the same as the maximum voltage value σ_max, and the results numerical simulation. The existing differences in the values of the minimum stress can be explained by the fact that the analytical solution does not take into account the features of fixation and geometry of the faces of the plate;
- it was found that in the presence of plate clamps, its destruction occurs later, and the amount of deformation differs slightly from the similar value of the plate without clamps so that under the same load, the fixed plate stretches a little more. This can also explain the slightly higher value of the experimentally calculated voltage value σ_max in comparison with the results of analytical and numerical calculations.

Conclusion. That is, we can assume that the larger the hole in the plate, the greater the difference between the experimental results and the results of numerical calculation, due to the effect of fixing the plate on its VAT.

References:

1. Martin H. Sadd. Elasticity Theory, Applications, and Numerics Fourth Edition / Martin H. Sadd. – London, UK, 2020.

UDC 629.735.33.064.5

Hrachov A.

AVIATION ELECTRIC AND HYBRID POWER PLANTS

Introduction. In 2021, it is difficult to imagine life without air transport. It has become a necessary part of human life, allowing us to move anywhere on the planet for tourism or work. Every year the demand for aviation grows and aircraft manufacturers face the problem of how to meet the needs of users, make flights affordable and at the same time environmentally friendly.

Most modern aircraft use kerosene or other petroleum-based fuels as fuel. The problem with their use is the rapid reduction in oil reserves, which some scientists predict may run out in a few decades. The largest percentage of combustion products of aviation fuel is carbon dioxide.

One way to reduce carbon emissions is to introduce electric or hybrid aircraft engines.

To date, it is impossible to make an aircraft with a fully electric power plant, in the traditional scheme of hybrid and electric power plants there is a place for liquid fuel.

The main problem with the introduction of absolutely electric motors is the low energy density of lithium-ion batteries. Difficulties in aircraft design also arise because, unlike aviation fuel, which is constantly reduced in use and thus makes the aircraft lighter, the mass of the batteries remains the same, even if they are discharged. In most aircraft, fuel is stored in airtight compartments of the wing, because kerosene is liquid, but to use batteries one needs to change the design of the aircraft.

Scientific and technical results. During the development of the use of electric and hybrid power plants, we can identify four main options for the use of electric drive:

- Sequential circuit;
- Parallel circuit;
- Distributed parallel circuit;
- Integrated circuit.

An example of the use of a sequential scheme is the Zunum Aero Hybrid-electric Small Regional Aircraft project [1], which is partly funded by Boeing.

The light passenger aircraft Zunum Aero ZA-1 for 12 passengers is designed for a range of up to 700 miles (about 1130 km). The direct drivers in this project are two hooded fans installed on the sides of the fuselage, which are driven by electric motors with a capacity of 500 kW. As a turbogenerator it is planned to use one modified Ardident 3 turbo engine with a capacity of 1700 hp of SAFRAN.

A clear example of the use of a parallel circuit is Project 804 from United Technologies Corp. (UTC), which is promoted jointly with Pratt & Whitney Canada and Rockwell Collins. The project is a modified thirty-nine-seat passenger aircraft for local Bombardier Dash 8 Q100 airlines. The aircraft is equipped with two hybrid main power plants with a total capacity of 2720 hp

(2 MW) each. The ratio between the gas turbine engine and the electric motor is equal to 1360 hp (1 MW) [2]. It is planned to place batteries and control and switching devices under the floor of the passenger cabin. According to the statements of the UTC developer, the use of hybrid technologies will reduce fuel consumption by up to 30% for routes with a range of 370 to 460 km. The flight of the demonstration aircraft is expected in 2022.

At present, with regard to the spaced parallel scheme, it is difficult to give vivid examples of aircraft designed by using this circuit. However, this approach offers numerous advantages over installing an electric motor on a low pressure shaft of a gas turbine. Because the conventional system is separated from the electrical system, the design and operation of the traditional and electrical systems is independent. As a result, the modern design of the gas turbine is not disturbed by the introduction of the electrical system.

The last approach to the hybrid-electric system to be considered is the so-called integrated system [3, 4], which consists of the electrifying part of the main cycle of the gas turbine. Currently, only a few publications on this topic are available, which are still in their infancy.

Conclusion. The full advantage of hybrid and all-electric aircraft can only be demonstrated by deploying a truly holistic approach to the integration of hybrid-electric and all-electric propulsion systems at the aircraft level. To determine the full potential, innovative approaches to electrically driven power systems need to be further analyzed and thoughtfully integrated at the aircraft level. It is expected that the search for synergistic integration of the propulsion system at the aircraft level due to the closely intertwined coupling with the glider, as well as with other systems on board the aircraft will lead to drastic changes in modern aircraft.

Therefore, today, one of the promising areas of aviation development is the introduction of hybrid and electric aircraft engines.

References:

1. Dieter, S. Evaluating Aircraft with Electric and Hybrid Propulsion.
2. Warwick, G. UTC'S Electric Transfomation // Aviation Week &Space Technology – 2019 – April 8-21– p.56 – 58.
3. Oliver Schmitz and Mirko Hornung. Methods for Simulation and Analysis of Hybrid Energy Propulsion Systems. In Proceedings of the 62nd Deutscher Luft- und Raumfahrt Kongress (DLRK), Stuttgart, 2013.
4. Oliver Schmitz. Fahrzeugtriebwerk, Fahrzeug mit diesem Fahzeugtriebwerk und Verfahren zum Betrieb dieses Fahrzeugtriebwerkes, 2012.

UDC 629.12.053

Hrechko M., Ponomarenko S.

INITIAL ALIGNMENT OF STRAPDOWN INERTIAL NAVIGATION SYSTEM OF SPACE AIRCRAFT ON PERTURBED BASIS

Introduction. Various projects of aerospace systems (ASS) and space unmanned aircraft (SUA), air launch method, composition of the ASS information subsystem, characteristics of ASS and SUA navigation systems and the task of the initial alignment (IA) in flight of the strapdown inertial navigation system (SINS) of SUA (Fig. 1), which is fixed under the wing of the aircraft carrier, in the presence of perturbations of the base. The perturbations are caused by vibrations and elastic deformations of the carrier aircraft.

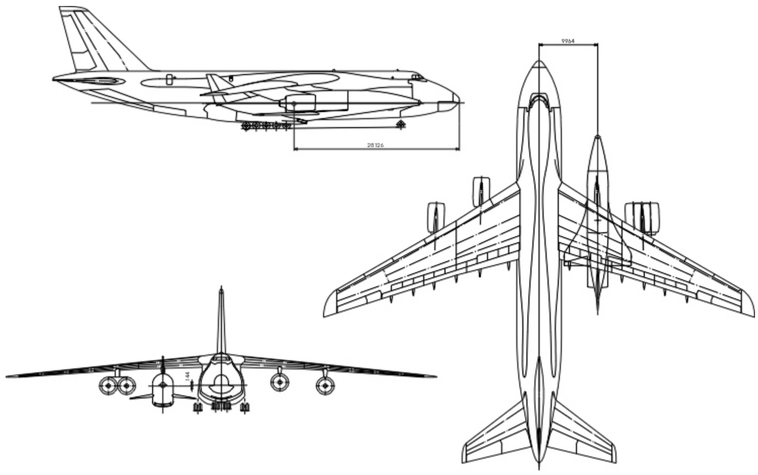


Fig.1. ASS project based on the An-124 Ruslan carrier aircraft with the option of placing the SUA under the wing

The IA task is analyzed in details before the air launch of the SUA. Up to the start, SINS of SUA is disabled in order to avoid the accumulation of errors. The solution of the problem IA SINS of SUA (exhibited system) is based on the using of reference information from the INS of the aircraft carrier (the system on which the exhibition takes place). During the flight both navigation systems can transfer information to each other after the SINS of SUA is switched on. The task of the IA is the transmission values of the navigation parameters of the carrier aircraft (speed, coordinates and angular orientation) with minimal distortion at the time of separation of the SUA in the SINS of this SUA to initiate its work. This method of IA is called "transfer alignment".

Scientific and technical results. The methods IA of SINS according to the information from the reference INS of the carrier flight are distributed according to the type of information that is used for problem solution of the IA, namely its own information about mutual angular orientation, acceleration and velocity of inertial systems. Table 1 shows the advantages and disadvantages of the three main methods of transfer IA of SINS.

Table 1. Features of the three main methods of transfer IA of SINS

Method name	Advantages	Disadvantages
The method of angular coordination	In combination with other methods of the initial alignment achieves greater accuracy of the initial alignment	Has limited using. Bending deformations of the carrier, errors in the installation of the system and errors in the suspension of the aircraft, there are difficulties in the alignment due to the coordination of the master and slave systems
Acceleration vector matching	Simplest of algorithm	Measurements for the algorithm are perturbed as inertial sensors are installed on board the SUA
Speed vector matching	In the process of integrating the accelerometer readings, a smoothing effect appears	It is necessary to have a mathematical model of SINS errors
		It is necessary to have a priori statistical information about existing errors and disturbances in the system
		To use this method, the carrier must perform a maneuver type "snake"

The task of the initial alignment of SINS on a perturbed basis is reduced to the standard task of Kalman's type assessment.

For this problem, there are two ways to take into account the influence of vibrations and elastic deformations of the aircraft carrier on the problem of SINS IA. The first is to determine the characteristics of elastic deformations of the carrier structure (tones of elastic deformations and amplitude of oscillations at a given point of the structure), calculate for each time linear and angular deviations of the suspension point SUA due to these perturbations and take them into. The second is to present the vibrations and elastic deformations of the aircraft carrier in the form of noise, which is distributed according to the normal law with known mathematical expectation and variance.

During the study, was obtained the information of tones elastic deformations of the wing An-124 aircraft carrier and the characteristics of its INS, the mutual location between the INS of the aircraft carrier and SINS of SUA was determined.

Based on the analysis of SINS IA methods on perturbed basis and features of methods considering vibrations and elastic deformations of the carrier aircraft, so were chosen the "transfer" IA method and the IA method with considering vibration and elastic deformations of the aircraft carrier in the form of noise.

An algorithm with sequential processing of measurements with reduction of the covariance matrix of the system to an upper triangular shape was chosen as an algorithm of Kalman's type. This algorithm is characterized by low computational costs and protection against degeneracy of the covariance matrix. The simulation modeling of the SINS IA problem of SUA was performed in such a way that the average value of the oscillation amplitudes at the SUA suspension point was chosen as the noise RMS. The best accuracy of the initial angular orientation of SINS and INS was obtained by angular matching of inertial systems.

Conclusion. The results of mathematical modeling show the efficiency of the proposed method and algorithms for solving the problem of SINS IA on a perturbed basis.

UDC 629.735.33

Kirkosov D., Kyrylenko M., Ryabkov V.

COMPARATIVE EVALUATION OF MODIFICATIONS OF DOMESTIC LIGHT TRANSPORT AIRCRAFT

Introduction. Light domestic transport aircraft An-26 and An-32 are widely used both on airlines of Ukraine and other countries. [1]

Further development of these aircraft is realized by creating their modifications with increased efficiency (m_{pl}·L), where m_{pl} is the mass of payload, and L is the range of its transportation.

The An-132 modification has already existed, based on the use of the PW150A foreign engine, which significantly increased the value of L. [2]

Scientific and technical results. In this work, to increase the performance of the An-32 aircraft, it is proposed to use domestic D436-148 FM type turboprop engine as an import substitution, which allowed to form the parameters of the new modification of the An-132 (U), which meets modern requirements for aircraft of this weight category based on the type dependencies:

$$\left(m_{pl}, L\right) = f\left(\overline{\text{B}}_{lc}, \text{A}_{hc}\right),$$

Where $\overline{\text{B}}_{lc}$ is unit cost during the life cycle of aircraft, A_h hourly costs of a commercial flight.

This approach has been implemented during the development of a generalized modification of the An-132U on the basis of regional transport aircraft An-26, An-32, An-32B. In performing this task, it is assumed that the performance of the An-132U modification should exceed that of the An-32B by 25 %, the criterion of unit cost should be at the level of world values - 0.4 dollars per t km flight, and the cost of aircraft hours should not exceed 2000 dollars/hour.

Table 1. Indicators of the effectiveness of this modification

Modifications / Parameters	An-32B	An-32	An-26	An-132U
Life cycle cost, USD	73510	73510	67510	10010
Criterion of unit cost during the life cycle, USD/t km flight	0.59	0.59	1.55	0.39
The cost of aircraft hour, dollars	2100	2100	2250	2000

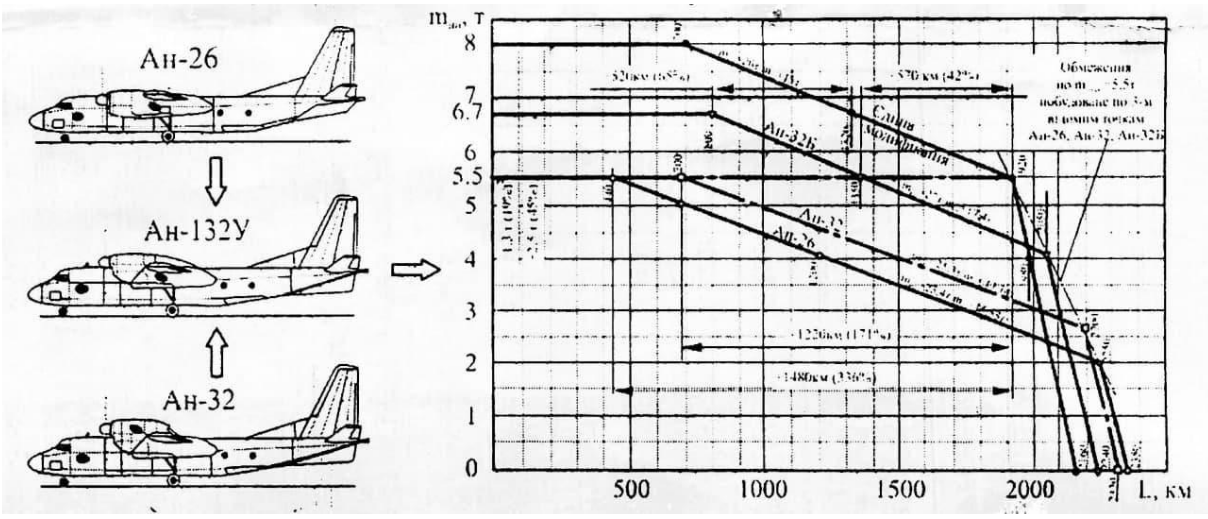


Fig. 1. The results of the formation of "load-range" characteristics of this modification.

Conclusion. An important result of handling the problem to form the technical parameters of the An-132U, as well as its economic indicators [3] in terms of domestic production provides this aircraft a complete advantage among light transport aircraft operated by airlines around the world.

References:

1. Krivov, G. A. Mirovaya aviatsiya na rubezhe dvadtsat' pervogo stoletiya. promyshlennost', rynki. [Tekst] / G. A. Krivov, V. A. Matviyenko, L. F. Afanas'yeva. Kiyev, KVP, 2003 – 295 s.

2. AN-132D Preliminary ground and flight tests first stage. Tekhnicheskiy akt № 132D.700.024.DZ-117GP Antonov, Kiyev, 2017. – 72s.

3. Los', A.V. Ekonomicheskaya neobkhodimost' sozdaniya modifikatsiy otechestvennykh voyenno-transportnykh samoletov [Tekst] / A. V. Los' // Aviatsionno-kosmicheskaya tekhnika i tekhnologiya: sb. nauch. tr. Nats. aerokosm, un-ta im. N. Ye. Zhukovskogo «KHAI». – Khar'kov, 2019. – Vyp. 7/159. – S. 6 – 11.

UDC 629.735.33

Kizim D. Kapitanova L.

IMPROVEMENT OF AERODYNAMIC CHARACTERISTICS OF A PROFILE WITH A LOW RELATIVE THICKNESS

Introduction. The purpose of the scientific work is to combine the deflected nose and the slat in order to calculate the change in the lift coefficient and prove that this combination will be more advantageous than the flap in relation to the C_{ymax} ratio to the unit mass.

Scientific and technical results. In the modern world, the most key point in air passenger transportation is economy. It can be measure by different methods, the consumption of kerosene per flight hour, per kilometer, or passenger. The bottom line always comes down to one thing, you need to lower this characteristic as much as possible and the savings in 1-2%, or even 5%, these are indicators that allow airlines to save millions of dollars a year.

There are two ways for lowering this characteristic:

Improving the performance of the engine, in particular its efficiency and consumption.

Improving the flight characteristics of the aircraft, reducing its frontal, inductive drag, or frictional drag.

In this work, the flight characteristics of the aircraft will be improved. Laminar profiles have low frictional resistance, since the air flow is laminar on most of the airfoil, which significantly reduces frictional resistance. Symmetrical profiles, at zero angles of attack, are devoid of inductive resistance, since there is no overflow of air from the zone of a more rarefied pressure to an increased one. However, all these profiles have one significant drawback, they have a low lift coefficient and that is why they are not used in large quantities. Mechanization of the wing helps to increase the coefficient of lift, in particular the wing slats, deflected nose and flaps.

The flaps increase the airfoil flow area and change its curvature, thereby increasing the lift coefficient C_{ymax} by 0.7 - 0.8 so that it reaches 1.8 - 1.9, however, this decreases the critical angle of attack α_{max}.

Slats, on the other hand, increase the critical angle of attack αcr, which increases the lift coefficient C_{ymax} by 0.5 - 0.6, which makes them more advantageous in relation to the mass.

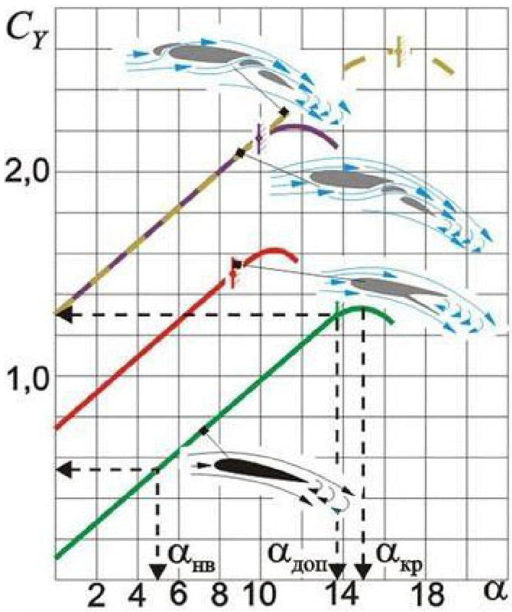


Fig. 1. Dependence of C_y on α.

The operation of the deflected nose, similar to the operation of the slat, increases the lift coefficient C_{ymax} by 0.5 - 0.6.

As mentioned earlier, the average increase in lift coefficient C_{ymax} in both cases is 0.5 - 0.6. However, when the slat and the deflectable nose are aligned, the C_{ymax} will decrease when considered separately. However, the gain in lift-to-mass ratio will be more beneficial than the flap.

Conclusion. This work confirms the feasibility of using such a design from an aerodynamic point of view.

References:

1. Krivtsov, VS Fundamentals of aerospace technology [Text]: a textbook for higher educational institutions (direction "Aviation and astronautics") / VS Krivtsov, Ya. S. Karpov, MN Fedotov. Part 2. - X .: Nat. Aerospace un-t "Khark. Aviation in-t ", 2003. - 901s.

UDC 624.011.72

Komarov B., Zinchenko D.

GLUED BAMBOO-WOOD COMPOSITE IN THE MANUFACTURE OF AVIATION STRUCTURAL ELEMENTS

Introduction. The price for personal aviation has not changed much despite the time that has passed since the first flight and remains a lot of only well-to-do people or enthusiasts who also spend a lot of money on creating their own aircraft. The use of bamboo composites can serve as a good boost for small aircraft due to their availability and high strength characteristics about weight.

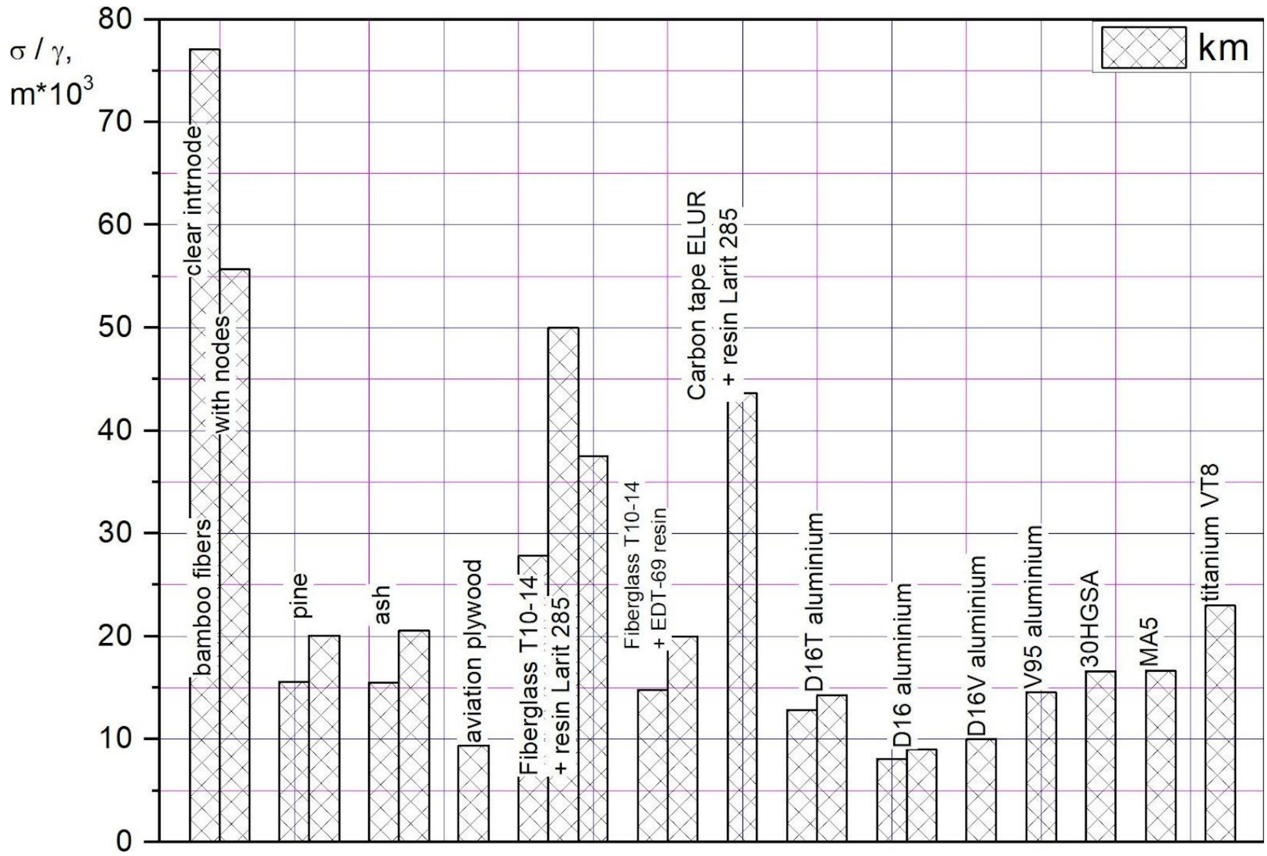
A lot of research is being carried out in the field of materials, bamboo is no exception. Nevertheless, very few works on this topic have been written in the direction of aviation. The novelty of the proposed study in the fact that at this time not available a final review with conclusions based on bamboo-composite tests of the strength for aviation use. The study allows to make sure that the use of bamboo composites exists among modern materials, especially considering environmental friendliness.

Scientific and technical results. According to the results of the study, it can be said that the use of processed bamboo is advisable in aviation. It has a fairly high strength-to-weight ratio. The density of bamboo wood is approximately 500 kg/m^3, and the average specific strength reaches 130-240 kN·m/kg, which is 1.2 and more times higher than that of wood used in aviation. And it practically reaches steel and aluminum alloys. Experimental results have shown that glued bamboo beams have better properties by more than 10% in comparison with monolithic bamboo segments presented in the source of authors Juan Francisco Correal, Juliana Arbeláez (2010) "INFLUENCE OF AGE AND HEIGHT POSITION ON COLOMBIAN GUADUA ANGUSTIFOLIA BAMBOO MECHANICAL PROPERTIES".

Low cost and easy to manufacture. High flexibility (Graph 7.) allows the production of many elastic elements: such as spars, frames, landing gears, and many other structural elements.

Also, an inalienable advantage is the lack of fatigue strength and the durability of the structure with practically no reduction in strength over time. After all, bamboo weakly absorbs moisture. Finally, bamboo is much more resistant to fire than wood and therefore offers much higher safety.

Bamboo load-bearing beams are not always amenable to restoration and repair like wood, so restoration of bamboo beams is not safe and unacceptable for aviation. So, the rule according to which scarfed joints used in the restoration of vintage planes most developed countries will only issue an airworthiness certificate if all such joints have used an angle no less than 1: 8 cannot use. Experiments with repaired bamboo beams have shown that the glue joint reduces the strength.



Graph 1. Elastic modulus σ/γ ratio for aviation materials.

In the following experiments, it is possible to check the strength characteristics of composite sandwiches and the stability and flammability of bamboo beams without treatment and after impregnation with compounds.

Conclusion. This job showed that the use of glued bamboo beams and wood is very promising in the creation of highly environmentally friendly planes. From the history presented in several sources, it became known that this is a very wear-resistant material that burns poorly and does not absorb moisture well, even pipes are made of it. Described defects and shortly how to sort the bamboo, which is very important because this greatly changes the characteristics of both semi-finished products and final products of beams.

The choice of glue in the production of beams is of great importance, high-quality PVA in terms of price-quality ratio is the best option for making slats. And polyurethane for gluing slats together and making beams.

Of the tests, glued bamboo beams were 10-15 percent stronger than monolithic beams for the same weight. And more than 20 percent better parameters than aircraft wood at a lower cost.

With further research, it is possible to create sandwiches with the best parameters from bamboo beams and glass-carbon-kevlar plastic and compare them.

UDC 533.65.013.622:629.735.33

Kotelnikov V., Kapitanova L.

DEVELOPING TAKE-OFF AND LANDING CHARACTERISTICS TO OVERCOME MARKET COMPETITION

Introduction. Current situation in the world aviation industry puts leading aircraft manufacturers in a difficult position - most of the up-to-date innovations are already implemented in existing aircraft and presented on the market. There should be a unique parameter, which would significantly increase the value of the new aircraft. One of the most important and complicated parts of any flight are the take-off and landing stage. They may seem secondary, compared to the whole aircraft run, but you will be surprised with the importance of their role. By these parameters, the airplane can be denied to maintain or even land in the chosen airport. But the good thing is that take off characteristics can be improved quite strongly. In this research we will look for extraordinary ways to improve them.

Scientific and technical results. Kruger flap, more common high-lift devices as the slat and the flap, boundary layer control method – all these tools are aimed to advance lift characteristics of the wing and allows it to perform on higher AOA by changing airfoil parameters in normal flight without changing the initial data.

All the above types of improving runway performance are pretty well-known, are already implemented in most aircraft, so they can't make a serious competition. But each aircraft has a powerful instrument – the engine, that can and should be used in a useful way. There is a chance to use an experimental method, based on an aerodynamic trick called Coanda effect. It states that air, passing through specially-formed nozzles, performs air adhesion to the blown surface, which can help to increase the flaps utility on the principally another level. Engines should be located on the front top of the wing in that way, to make jet exhaust go along the suction surface, directly to the advanced flaps. This maneuver will increase Cy coefficient from 1.5-2 on average existing plane to 3-4 on plane with mentioned effect.

Conclusion. Using the Coanda effect will improve takeoff and landing performance and make new aircraft more valuable on the market.

UDC 629.326.2

Kryszkiewicz M., Potęga B., Retych K.

INFLUENCE OF MODERN AERODYNAMIC DEVICES ON MOTORCYCLE AERODYNAMICS

Introduction. The Student Association for Vehicle Aerodynamics (abbreviated SKAP in Polish) at the Warsaw Technical University has been designing and building extremely fuel-efficient vehicles for over 15 years. Work on another project – an electric motorbike Perun for the Moto Student Competition began in 2018. Experience gathered during SKAP's first start in that competition in 2020 points out a few changes that need to be made to the motorcycle's design before the next edition.
In recent years much effort has been put into improving the aerodynamics of racing motorcycles and SKAP wants to follow suit. Aside from fairings shape optimization, addition of smaller aerodynamic devices, such as winglets, provides room for further increase in aerodynamic performance. First step in integrating these into a motorcycle design is a basic analysis of winglets in two different locations and configurations as below.

Scientific and technical results. The geometry was prepared for meshing in Ansys SpaceClaim. BOIs were added in areas of particular interest (e.g. around the front fairing and the rider's head). Numerical calculations were performed using Fluent software with the k- ω SST turbulence model. Prism layers addition helped achieve the y+ parameter of <1 on the motorcycle fairings, wheels and rider for accurate boundary layer modelling. Airflow velocity was set to 44 m/s (Perun's top speed is around 50 m/s). First, the airflow around the motorcycle without any extra aerodynamic devices was simulated to serve as a benchmark. Then, initial designs of front winglets and small wings in front of the rear wheel were added in separate cases. Their position and geometry are based on similar examples from racing motorcycles and adapted to the Moto Student competition regulations. Profiles used were: NACA 23015 for the front winglets and S1223 RTL for the rear wings.

Pathlines for the benchmark case (without extra wings) displayed below highlight areas with the least turbulence, where extra aerodynamic devices could be placed. Winglets position proved incorrect – presence of lower pressure region just above the winglet (as shown below) causes a decrease in downforce.

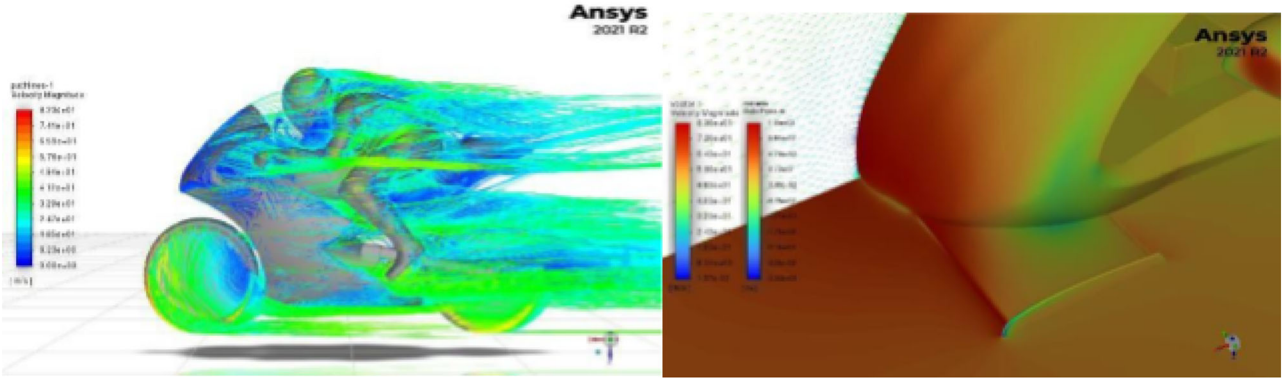


Fig.1. Visualization of airflow.

The underside of the rear wings (left below) directs the flow well, there is almost no flow separation and all three wings generate downforce. On the other side (right below) vortices form on all the wings (especially on the first one), lowering the whole element's performance.

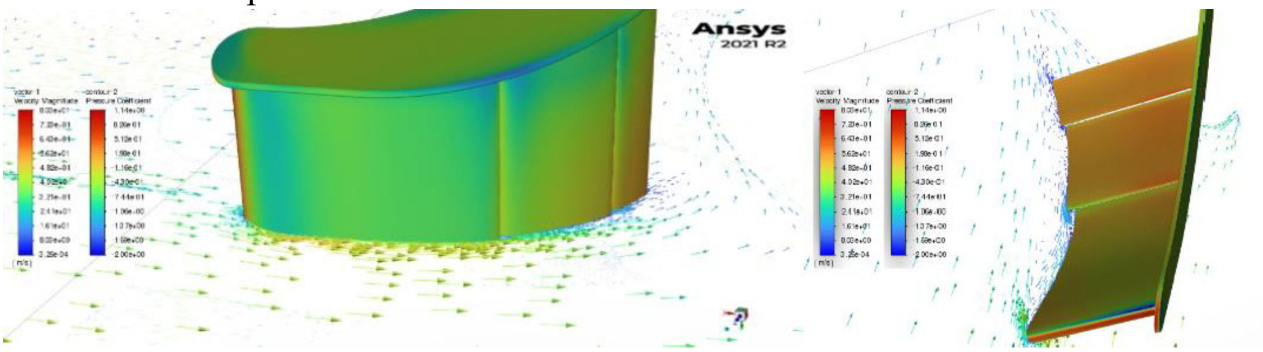


Fig.2. Visualization of pressure and airflow behind the wings.

Table 1. Shows the forces generated by the wings:

Case	$^{F}d\ wing\ ^{[N]}$	$^{F}l\ wing\ ^{[N]}$
No extra elements	–	–
Front winglets	3.85	15.6
Rear wings	4.07	10.6

Conclusion. While the extra forces generated by the wings are significant, further research needs to be conducted in order to determine optimal positions for these elements. Because of hardware and CFD limitations, the final solution should be tested in an aerodynamic tunnel and on track.

Moving the front winglets down to a region with less turbulence, increasing their angle of attack and changing the profile to e.g. S1223 RTL would result in a higher downforce. The front fairing was designed without extra wings or winglets in mind, so its shape should also be tweaked, if the extra devices are to be used.

The rear wings are placed in a region of high turbulence. A slight change in position and a decrease in angle of attack could potentially eliminate the vortex forming on the upper side of the first wing. However, they cannot be moved much lower or they would rub against the track in tight corners. Counterintuitively, addition of this element significantly increases drag force generated by the rear wheel, even though the total drag decreases.

UDC 629.735.33.075

Kyrylenko M., Kapitanova L.

INFLUENCE OF MODIFICATION CHANGES IN LIGHT TRANSPORT AIRCRAFT ON THEIR MOVEMENT DURING TAKEOFF AND LANDING

Introduction. The most famous light domestic aircraft is the An-26 and its modifications An-30, An-32, An-32B.

Aircraft modifications of this weight category are subject to changes in order to increase their load lifting capacity, range and increase fuel efficiency. [1]

Scientific and technical results. Such a process has been analyzed on the examples of modifications of the An-26, An-30 and An-32 airplanes based on the dependences of the type [2]:

$$L_p \approx \frac{P_0}{\rho_0 g C_{yalo}\left(\overline{P}_{av} - f_1\right)} .$$

Where $\overline{P}_{av}$ and f_1 are average values of thrust-to-weight ratio and drag coefficient along the take-off run.

Table 1. Results of the implementation of such changes are shown.

Parameters being modified	Modifications		
	An-26	An-30	An-32
Maximum takeoff weight, kg	24000	23000	27000
Take-off thrust, m	2 × 2820 hp	2 × 2820 hp	2 × 5180 hp
Takeoff run, m	870	770	880
Landing run, m	650	525	505

Conclusion. It follows from the above results that the proposed approach allows one to provide the required conditions for the modification base already during selection of the main parameters at the stage of its design.

References:

1. Los', A.V. Realizatsiya modifikatsionnykh izmeneniy pri sozdanii legkogo voyenno-transportnogo samoleta An-132D [Tekst] / A. V. Los' // Vestnik KrNU im. Mikhaila Ostrogradskogo. Vyp. №1. 2020 g. – S. 120.

2. Kapitanova L.V. Modelirovaniye konfiguratsii vzletno-posadochnykh kharakteristik samoleta pri proyektirovanii yego modifikatsiy / L. V. Kapitanova, A. N. Naumenko // Aviatsionno-kosmicheskaya tekhnika i razrabotka. – 2009. № 6 (63). – S. 19-23.

UDC 629.783

Pavlova V., Korobko I.

THE PROBLEM OF REPLACING XENON IN ELECTRIC PROPULSION ENGINES

Introduction. In the last few years there has been a growing interest in low-thrust electric propulsion engines used in astronautics. The achieved technological breakthrough in the creation of engines of this type allows to ensure the solution of a number of transport and utilization problems in near-earth space. Possessing a high velocity of the jet stream and a high impulse of the electric propulsion engine, it allows to increase the efficiency of maintaining low orbits of spacecraft. However, there are a number of aspects that limit the use of this type of engine. The main issue is the labor intensity of the xenon production process, which is used as a working fluid for a given type of engine.

So some authors have mainly been interested in questions concerning the kind of a working body and comparison of their characteristics.

Scientific and technical results. The characteristics of the engine with an anode layer depend on the used working fluid. When switching from traditional and well-studied xenon to other working fluids, it is necessary to know how the main parameters of the engine change.

In his work Dukhopelnikov D. V. [1] demonstrates results of comparison of anode layer thruster characteristics, when it operates on different working fluids. For comparison, argon and nitrogen were selected as the most promising substitutes. His results showed that the energy cost of thrust when operating on nitrogen is 2.5 times higher than on xenon, but it was not possible to determine the mass composition of ions in the nitrogen beam. Also, when nitrogen was used, the discharge current in the operating voltage range was 2 times higher than that on xenon. In addition, at almost similar flow rates of the working fluid, similar dependences of the current efficiency were obtained for all gases, while the mass efficiency of the engine when operating on nitrogen is on average 2 times less than on xenon.

Unfortunately, the transition to less popular, but still labor-intensive production gases, will not solve the problem, but will only postpone it in time. Therefore, alternative sources, which are not well examined today, have been proposed.

As reported by Dukhopelnikov D. V. [2], at altitudes from 200 to 300 km, the Hall-effect thruster can operate on outboard air as a working substance. This assumption makes it possible to significantly reduce fuel costs, as well as extend the service life of the spacecraft, since the main factor determining the operating time of the satellite is the amount of fuel on board [3]. In this case, the stock will tend to infinity, since it can always be replenished from the atmosphere. Important aspect to highlight is the environmental friendliness of using air instead of other gases. But the question that needs to be asked, however, is whether the test results will also be as encouraging as simulation results.

Unlike Dukhopelnikov D.V., Rymyantsev V. A. [4] states that a low power engine operated on krypton will be a better alternative in light of the lack of xenon. In his study he introduces test results that show that the usage of krypton gives values adjusted to usage on xenon with an increase in the density of the gas flow rate in the accelerating channel, but at the same time negative effects begin to manifest themselves. Such as a high rate of wear of the discharge chamber wall and a significant decrease in the specific impulse of the thrust after 150 hours of operation. All of the above means that these effects reduce the resource of existence of the entire apparatus, but allows it to perform work on all the necessary heights.

A typical solution of this problem was given by Ostrovskiy V. G. [5]. He proposes to use an iodine as an alternative propellant for electrojet engines. The annual production of iodine is many times greater than the production of xenon. It also should be borne in mind that the cost of one kilogram of iodine is ten times lower than the cost of one kilogram of xenon. Author states that usage of iodine paired with a movable discharge chamber and a thermal-emission cathode-neutralizer (that is, non-consumable) will make it possible to create a model of an engine with characteristics that will not fatigue with a xenon engine and sometimes even exceed. Tests have shown that such a model has a higher anode efficiency and specific impulse.

Conclusion. Collectively, these studies outline a critical role for usage of a proper work fluid for electrical engines. The planet's reserves are being depleted, the ecology is deteriorating. It is important to switch to greener and more renewable fuels as soon as possible, where it is available.

A key limitation of all these researches is poor financing. Such complicated matters require extensive investments in the construction of prototypes and their testing.

More research and testing are needed to replace the fuel for low-orbit satellites with a new kind of cheaper and greener working fluid. This direction is extremely promising, since replacing xenon at satellites performing specific tasks will significantly extend the period of their operation, and therefore will help in the fight against debris in low Earth orbit.

References:

1. Duhopelnikov D.V., Ryazanov V.A., Shilov S.O. Comparison of the characteristics of a model engine with an anode layer when operating on xenon, argon and nitrogen. Proceedings of higher educational institutions. Machine building. Moscow, 2018. No.7, p. 69-76.

2. Duhopelnikov D.V., Ivakhnenko S.G., Ryazanov V.A., Shilov S.O. On the application of hall thruster working with ambient atmospheric gas for a low-Earth orbit. Science and Education of the Bauman MSTU. Moscow, 2016. No.10, p. 57-71.

3. Schonherr T., Komurasaki K., Herdrich G. Analysis of Atmosphere-Breathing Electric Propulsion. IEEE Transactions on Plasma Science, 2015, vol. 43(1) pp. 287–294

4. Rymyantsev A.V., Saevets P.A. Development of a low power engine for operation on krypton. Bulletin of the Baltic Federal University. I. Kant Kaliningrad, 2016. No.3, p. 80-87.
5. Ostrovskiy V.G., Smolentsev A.A., Scherbina P.A. The iodine as an alternative propellant for electrojet engines. Samara State Aerospace University Bulletin. Samara, 2014. Vol.4, No.5(47), p. 131-136.

UDC 629.735.45

Pronoza. V.

APPLICATION OF POLYMER COMPOSITE MATERIALS IN HELICOPTER BLADES

Introduction. The main rotor (MR) of the helicopter is the main unit, which largely determines the flight technical, maneuverable characteristics, and the level of reliability of the helicopter.

Scientific and technical results. Changes in such indicators as resource, reliability, manufacturability, manufacturing cost, maintenance requirements will have a greater impact on the operating and depreciation costs, manufacturing costs. Composite materials are more and more widely used in helicopter construction. The use of polymer composite materials (PCM) in the rotor blades, will give a significant improvement in characteristics, namely:

– laying out the fibers along the action of the load (in the blades of a helicopter, this has a significant effect, since the blade during operation experiences significant tensile stresses);

– reducing the number of parts and reducing the complexity of manufacturing the blade;

– specific stiffness and strength characteristics of PCM are 2..3 times superior to well-proven titanium and steel alloys;

– significantly longer resource (PCM blades have a resource of up to 10,000 hours, while metal blades up to 2,000 hours), which directly affects the reduction of operating costs;

– reliability increases significantly in the presence of operational defects, since the crack propagation will proceed more "smoothly" due to the layered structure of the PCM.

The disadvantages of PCM blades include:

– manufacturing cost, as well as the cost of PCM components;

– creep under continuous loading, delamination;

– change in physical and mechanical properties, depending on temperature.

The installation of PCM blades on the MI-171A helicopter [1] made it possible to increase the maximum take-off mass by 5%, maximum flight speed increased by 10 km/h, the practical ceiling is 600 m higher, than with the standard metal blades. The kilometer fuel consumption of a helicopter with PCM blades decreased by 3–8% (depending on the flight speed).

The implementation of the possibility of reducing the mass of the blade and increasing the take-off weight of the helicopter allows not only to compensate for the increased cost of the PCM, but also to actually lead to a decrease in the total cost of the blade.

The results of flight tests of helicopters KA-15 and KA-18 showed that the use of fiberglass blades, instead of serial metal ones, made it possible to increase thrust by 4.6%, static ceiling 141%, payload 87.5%. After a flight of 3000 hours, the blades were removed, a technical check of the condition of the blades was carried out, the results of which showed that the blades could be further operated. Instead of fiberglass, glass carbon fiber blades (having a higher modulus of elasticity, 3 times compared to fiberglass), made it possible to reduce the load on the supporting system by 30%, while the resource of various units increased by 2-3 times [2].

The use of a double-contour spar on the KA-50 helicopter made it possible to increase the stiffness of the blade, which led to a decrease in the distortion of the blade profile when it was loaded [2]. Also, a double-circuit spar increases the survivability of the blade when it is damaged.

In the same direction, JSC "Motor Sich" is mastering the full cycle of manufacturing MR and TR blades from PCM, from laying the spar to complete assembly of the blade and flight tests. These blades will be installed for the modernization of MI-8 MSB and MI-24 helicopters. It is also planned to install new blades on the MI-2 MSB helicopter.

Conclusion. Having weighed all the advantages and disadvantages, we can conclude that it is advisable to introduce blades from PCM, which will give significant improvements in the characteristics of not only the blades, but also the helicopter as a whole.

References:

1. Ивчин В.А., Самсонов К.Ю. Результаты первого этапа летных испытаний вертолета – летающей лаборатории Ми-171А2. Научный вестник МГТУ ГА. 2014. №200. С. 63-69. URL: https://cyberleninka.ru/article/n/rezultaty-pervogo-etapa-letnyh-ispytaniy-vertoleta-letayuschey-laboratorii-mi-171a2/viewer.
2. Ганюшкин Ю. Приоритет за ОКБ Камова. Журнал «Вертолёт». 2003. №03. URL: https://military.wikireading.ru/h8FhEtVSLx.

UDC 629.05

Prytulenko V., Ponomarenko S.

CALIBRATION METHOD OF STRAPDOWN INERTIAL NAVIGATION SYSTEM WITH NON-ORTHOGONAL PLACEMENT OF SENSITIVE ELEMENTS

Introduction. Research in the field of development of strapdown inertial navigation systems is aimed primarily at solving two main tasks - improving the reliability and accuracy of these systems.One possible way to increase INS accuracy is to use high-precision sensors or calibrate the system to reduce its sensor error.

Scientific and technical results. The task of increasing the reliability of INS is often solved by using redundancy.Redundancy is achieved by introducing hardware losses through the introduction of spare elements.Ways to implement such a surplus are divided into:

1) use of the redundant number of measuring units or devices;

2) use of the redundant number of sensors of primary information in one measuring unit.

For the redundant inertial measurement unit with their non-orthogonal sensors placement figure1.

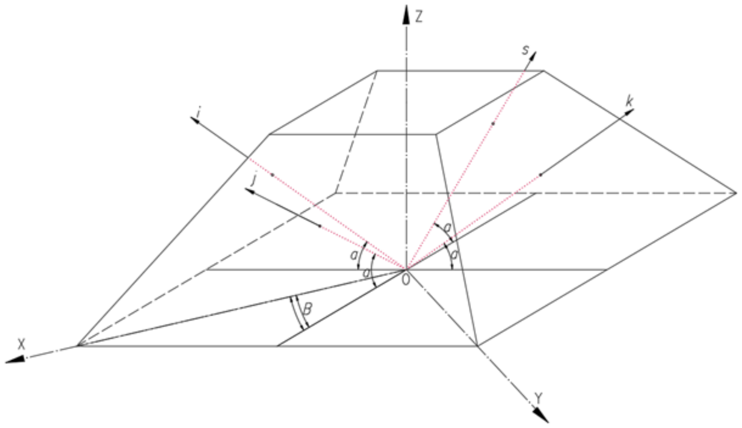


Fig.1. Where i, j, k, s- are the measurement axes of the primary information sensors;OX, OY, OZ - are the axes of the coordinate system of the unit;β - is the angle between the sensor and the axis of the coordinate system;α is the angle of inclination of the measuring axis of the sensor.

The general expression for formation of values of output signals of the block is received:

$$\begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{bmatrix} + \begin{bmatrix} \delta_{(1)0} + \delta_{(1)1} w_{(1)} + \delta_{(1)2} w_{(1)}^2 \\ \delta_{(2)0} + \delta_{(2)1} w_{(2)} + \delta_{(2)2} w_{(2)}^2 \\ \delta_{(3)0} + \delta_{(3)1} w_{(3)} + \delta_{(3)2} w_{(3)}^2 \\ \delta_{(4)0} + \delta_{(4)1} w_{(4)} + \delta_{(4)2} w_{(4)}^2 \end{bmatrix} = \left(\begin{bmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta & \sin\alpha \\ -\cos\alpha\cos\beta & \cos\alpha\sin\beta & \sin\alpha \\ -\cos\alpha\cos\beta & -\cos\alpha\sin\beta & \sin\alpha \\ \cos\alpha\cos\beta & -\cos\alpha\sin\beta & \sin\alpha \end{bmatrix} + \begin{bmatrix} \varepsilon_{(1)x} & \varepsilon_{(1)y} & \varepsilon_{(1)z} \\ \varepsilon_{(2)x} & \varepsilon_{(2)y} & \varepsilon_{(2)z} \\ \varepsilon_{(3)x} & \varepsilon_{(3)y} & \varepsilon_{(3)z} \\ \varepsilon_{(4)x} & \varepsilon_{(4)y} & \varepsilon_{(4)x} \end{bmatrix} \right) \cdot \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix},$$

Where w_i - the output signal of the i accelerometer; $\delta_{(i)0}$ - zero offset of the i accelerometer; $\delta_{(i)1}$ - error of the scale factor; $\delta_{(i)2}$ - square error; $\varepsilon_{(i)x,y,z}$ - errors of deviations of the measuring axis of the sensor from the nominal value on the corresponding axes; $g_{x,y,z}$ - projections of the measured acceleration on the corresponding axes.

Expression to relate the measured acceleration values to the accelerometer errors in the case of three arbitrary measuring axes calculated to the first order of smallness:

$$\tilde{G}^T\tilde{G} = G^TG + A_{W(3)} - A_{V(3)} \quad (2)$$

$$A_{W(3)} = 2W^T(VV^T)^{-1}\Delta_W, \quad (3)$$

$$A_{V(3)} = W^T(VV^T)^{-1}(\Delta_V V^T + V\Delta_V^T)(VV^T)^{-1}W, \quad (4)$$

Where W - matrix of the output signals of the sensors; V - matrix of orth of axes of sensitivity of sensors; Δ_V - errors of sensor installations; Δ_W - sensor errors; G - vector of acceleration of gravity; $\tilde{G}$ - vector of acceleration of gravity taking into account errors.

Expression to relate the measured acceleration values to the accelerometer errors in the case of a four-axis measuring unit:

$$\tilde{G}^T\tilde{G} = G^TG + A_W + A_V, \quad (5)$$

$$M = (V^TV)^{-1} \quad (6)$$

$$A_W = W^TVMMV^T\Delta_W + \Delta_W^TVMMV^TW \quad (7)$$

$$A_V = W^TVMM\Delta_V W + W^T\Delta_V MMV^TW - W^TVMM(\Delta_V^TV + V^T\Delta_V)MV^TW - W^TVM(\Delta_V^TV + V^T\Delta_V)MMV^TW \quad (8)$$

Figure 2 shows a general calibration scheme, where the redundant measuring unit mounted on a rotary stand converts the measured vector into a matrix of sensor readings.

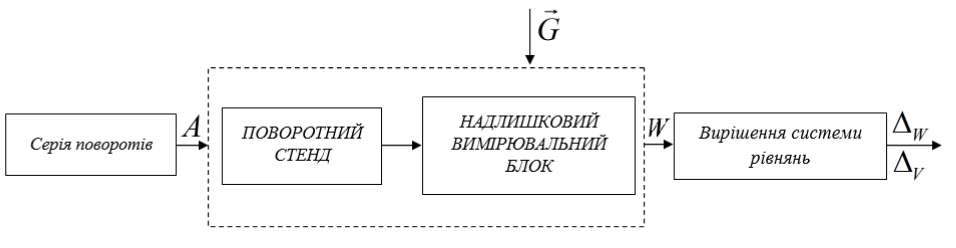


Fig. 2. Algorithm of the method of calibration of unprofitable measuring unit with non-orthogonal placement of sensors.

Where A - is a series of set turns of the block; $\vec{G}$ - vector of acceleration of gravity;W- is the matrix of sensor readings in the unit; Δ_V - matrix of errors of installation of sensors in the block; Δ_W - matrix of accelerometer errors.

Relevance. These systems provide complete information about the navigation parameters and they require a minimum amount of external information, which well guarantees their autonomy.Due to the ability to determine the angular position of the aircraft with a high frequency of information and high accuracy, SINS currently have no alternative.For satellite systems or unmanned aerial vehicles in conditions of limited mass and size characteristics, increasing the reliability of SINS is one of the leading tasks.The method using redundancy at the level of the measuring unit has much smaller mass and size characteristics and ease of implementation of the design of the unit, which plays a key role in such a system in comparison with the redundancy of the IMU.

Conclusion. Scientific and practical value of the research. The main objectives of this work are the theoretical justification and practical implementation of the method of calibration of redundant BINS with non-orthogonal placement of primary information sensors.To achieve this goal the following tasks were solved: analysis of the current state of methods of calibration of sensors and IMUs, theoretical substantiation and development of a method of calibration of redundant SINS with non-orthogonal sensors, analysis of the exact characteristics and functionality of the obtained calibration method.

Practical value valuable, first of all, for systems that require increased reliability of an inertial navigation system and in conditions of limited mass and dimensional characteristics of the system.

UDC 62.752

Ryzhkov L., Korlyakov Y.

SYNTHESIS of INDICATOR DYNAMIC VIBRATION ABSORBER

Introduction. When using a dynamic vibration absorber (DVA), one of the main issues is the circuit implementation of the damper and the whole scheme of vibration damping in general. The passive type DVA is characterized by the presence of the force interaction of the oscillating body and the inertial mass of the absorber, which is realized in the form of forces or moments of dry and liquid friction forces, elastic forces. Such absorberi are very simple in design, but one of the main obstacles in their use is the need to ensure this power interaction, as it requires a change in the design of the device. In the dynamic vibration absorber of indicator type, there is no mechanical connection between the oscillating body and the inertial mass of the absorber. The connection is provided by torque sensors and a control system.

Scientific and technical results. The method of calculation is considered and the efficiency of such vibration absorbers is analyzed. The obtained expressions for the optimal parameters of electromechanical DVA with asymmetric couplings as functions of one parameter, which takes into account both mechanical and electrical properties of the vibration damping circuit, show the advantage of electromechanical absorbers compared to known absorbers. The expressions generalize the known relations which are used in the theory of dynamic damping of oscillations and allow the synthesis of schemes in which electromechanical converters of forces (moments) are received.

Due to the fact that in such schemes the mass of the absorber is not significant, DVA can be made miniature. It is also important that there is no direct force interaction of moving bodies, which simplifies the design of circuits with DVA.

The use of DVA of indicator type is a radical means of increasing efficiency of the schemes with dynamic damping of oscillations.

The advantage of such schemes is the ability to change the structure and parameters of the absorber and the scheme as a whole without changing the design and parameters of the main device.

Conclusion. It is shown that possible instrumental errors have a negligible effect on the efficiency of dynamic vibration damping.

UDC 621.791.725

Shashko YU., Kulik O., Adzhamskiy S.

BLASTING AS AN ALTERNATIVE TO CLASSICAL SURFACE TREATMENT METHODS IN ROCKET AND SPACE TECHNOLOGY DETAILS OBTAINED BY THE ADDITIVE METHOD

Introduction. In the last decade, additive technologies have become very important in the manufacture of parts in mechanical engineering, in particular in rocketry. This simplifies the manufacturing process of products, improves their quality, reduces production time and the number of stages of the technological process, and so on. However, parts made by the additive method such as closed blades have serious drawbacks, and the very need for post-processing of closed surfaces, which is very difficult to do with traditional methods and sometimes impossible. In this paper, we will consider a solution to the problem of finishing the surface of the parts of the RCT responsible, namely - the blades of the turbines of the closed monocles of the turbopump unit.

Scientific and technical results. The object of the study is the development of the process of finishing the surface of the impellers of the turbine impeller made of heat-resistant nickel alloy Inconel 718, samples of the blades are made by additive method using SLM technology. The purpose of the work is to practice the mode of processing the closed surfaces of the blades.

In previous works, a detailed comparative analysis of existing methods of surface treatment of parts in mechanical engineering, identified one of them, which in the opinion of the authors can serve as an alternative to other methods without compromising surface quality, while reducing time and resources. This method is blasting.

Blasting is a jet treatment of surfaces of various types with the use of abrasives. In the process of blasting in a stream of compressed air is a mixture of abrasives of a specific fraction and concentration. Under the influence of compressed air, the abrasive particles inside the jet come into contact with the surface of the part and smooth the microroughness, while reducing the roughness. Depending on the type of abrasive, there are sandblasting, soft blasting and cryogenic blasting. This paper considers an example of soft blasting using sodium bicarbonate (soda) as an abrasive.

In the course of experimental work and working out of modes on samples of blades it was possible to reduce roughness from 1-2 to 3-4 classes, which is an excellent indicator at an early stage of working off.

Conclusion. The results of experimental work confirm that this method of processing, with subsequent modernization, has every chance to become the main and key method in post-processing of parts of this type and configuration.

References:

1. Blasting: Gid po vysokoeffektivnoy abrazivostruynoy ochistke / Kozlov D. YU.. — Yekaterinburg: OOO «ID „Origami“», 2007. — s. 216.
2. Andreas W. V. Blasting and Coating of Steel Structures: Germany. 2018. 205s. DOI10.1016/B978-1-85617-395-7.X5000-8.
3. Anna Rudawska. Surface Treatment in Bonding Technology. Product Copyright: Faculty of Mechanical Engineering, Lublin University of Technology, Lublin, Poland. 2019. S. 284.DOI 10.1016/C2018-0-01281-5.
4. Morgunov, Ju.A. Additivnye tehnologii dlja aviakosmicheskoj tehniki / Ju.A. Morgunov, B.P. Saushkin // Additivnye tehnologii. –2016. – T. 1. №1.– S. 30-38.

UDC 62-1/-9:62-6:62-8

Shuhayeu P., Martsinchyk A., Milewski J.

FEASIBILITY OF PROTON EXCHANGE MEMBRANE FUEL CELL IN UAV APPLICATIONS

Introduction. Unmanned aerial vehicle (UAV) — as it comes from the name means the absence of the human presence on the aircraft. There are a lot of different possibilities to use UAVs in a lot of different fields. In civilian areas, UAVs are used in scientific research, monitoring wildfire, maps creation, photography, etc. Total time spent in flight (endurance) plays a significant role in the UAVs development. Endurance depends on many parameters, e.g., weight, size, payload, and strongly depend on the power supply source. Nowadays, the power supply for UAVs is mainly either combustion engines or electric. Only electric supply system will be taken into consideration in this work.

Among the battery-based solutions, Lithium-ion (Li-ion) batteries are the most common choice. Li-ion batteries have high power and energy density, low self-discharge rates, long life, and recycling. They have better key parameters for UAV than other types of batteries, e.g., cell voltage, specific energy, etc. One of the promising and highly investigated technology nowadays is a fuel cell. It has a large variety of scales and possibilities, from stationary to vehicle motive power. It has high efficiency, zero-emission, high specific energy density, zero noise pollution, etc.

A fuel cell is an electrochemical device that converts chemical energy fully into electrical without any intermediate stages. A fuel, typically H2, goes to the anode side, where it oxidizes and splits into electrons and ions. Electrons then go through an external circuit, while ions go through the electrolyte to the cathode side where oxidant, which usually is ambient air, is supplied. At the cathode side, oxygen meets with the ions and electrons to complete the reaction and produce water and heat as a bypass product.

Scientific and technical results. Chosen UAV for fuel cell reconfiguration is A.R.C.H.E.R. Designed by a team of students from Warsaw University of Technology. The cruise power of that UAV is about 800-1000 W, at full payload estimated to take 1300 W. Without payload, on two 6S LiPo batteries, this UAV is capable 28 minutes of flight endurance.

MODEL SIMULATION. The theoretical model was realized in Aspen HYSYS software (Fig. 1). The simulation was done based on the reduced model approach.

As the initial parameters, there can be set up pressure across the fuel cell, the molar flow of the hydrogen, and inlet temperatures of the flow. The rest of the parameters are calculated by the software. The main parameters that should be compared between battery and fuel cells is energy density. For two batteries energy density (gravimetric) is estimated to be 207 Wh/kg. That amount of energy density gives the opportunity to approximately 30 minutes of flight endurance. At the same time, 50 grams of hydrogen gives about 1665 Wh/kg (based on LHV). If the volumetric energy density is taken under consideration, hydrogen stored at 300 bars has density ρ = 20 kg/m^3, which results in energy density equals to 666 Wh/L. Two batteries with dimensions listed in table 3 have a volumetric energy density of 486 Wh/L. To increase the endurance from 30 minutes to 1 hour, it is necessary to double the mass of the battery. In the case of the fuel cell, the whole system (fuel cell, fuel, tank) would have a mass of about 2,2 kg, against 3 kg from the battery. The further increase in the endurance will result in a rapid increase of the battery mass and volume. Mass of the fuel cell stack, on the other side, will remain the same, only the mass of the fuel and tank (with the volume of the tank) will increase. Fig. 2 presents the difference in mass depending on the operation time.

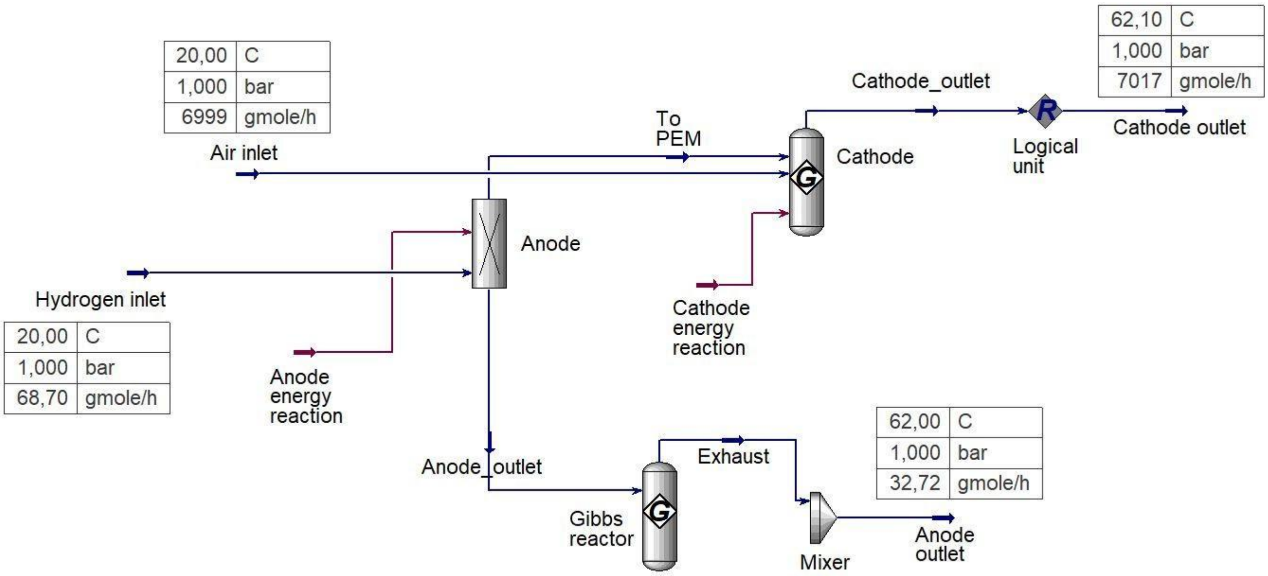


Fig. 1. Simulation scheme.

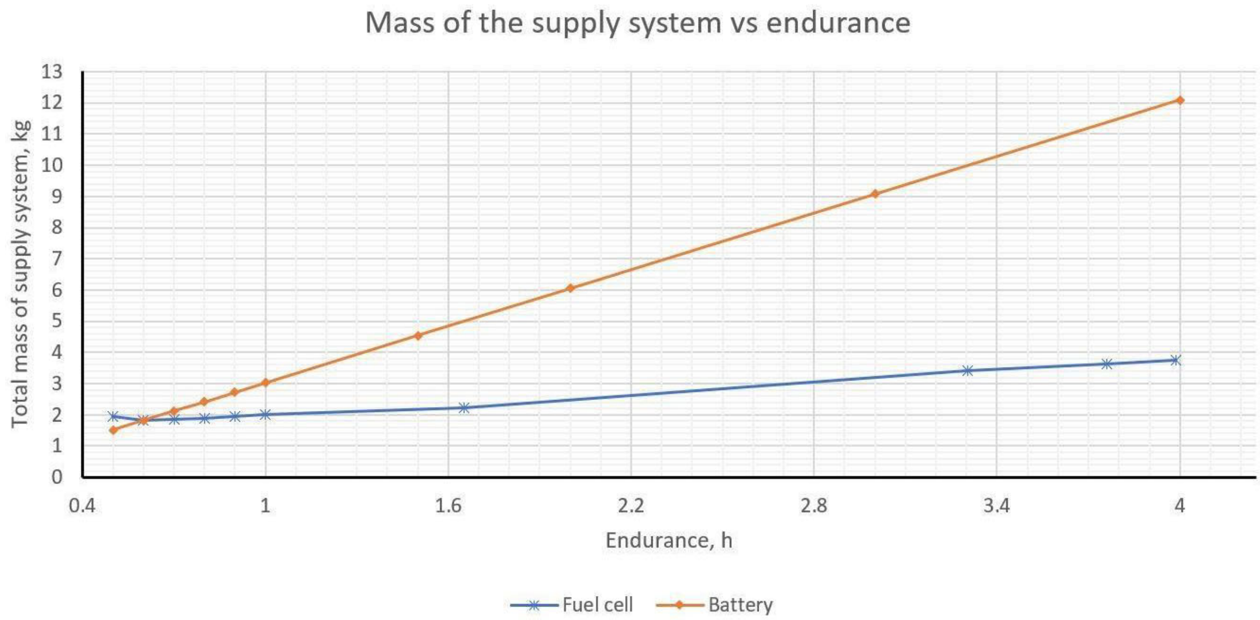


Fig. 2. Shows the point where the application of the fuel cell is not feasible. it appears that for this exact case, below 36 minutes of operation application of fuel cell is senseless.

The mass of the components was estimated based on the commercial open source offers. The mass of the whole stack is 901 g.

PROPULSION SYSTEM. Based on the parameters of the battery there was calculated, that mass of the batteries took 12 % of the MTOW. As was discussed with the UAV designers, up to 20 % of the MTOW may occupy the propulsion system. A target for the fuel cell stack is about 1 kW of cruise power with the ability to access 1.5 kW of maximum power. With the efficiency of the cell achieved during the modeling process (η_{eff} = 62.03 %), the UAV would need 1612.12 Wh of the hydrogen. From the LHV of H2 (LHV_{H2} = 33313.9 Wh/kg), 50 grams (including about 4 % of the fuel reserve) of hydrogen will provide enough energy.

To store hydrogen, only compressed pressure tanks are considered. Type III carbon overwrapped aluminum pressure vessel operating at 300 bar is a good choice for hydrogen storage from the economic and technical point of view.

DISCUSSION. One of the problems of unmanned aerial vehicles is in their endurance. Low-temperature fuel cells can solve this problem because of the very high specific energy of hydrogen used as a fuel. It gives the UAVs a significant amount of power and, as a result, better endurance. Simulation and optimization helped to achieve the required power capacity of 1500 W.

Mass of the whole fuel cell supply system took 17.6 % of the total MTOW, against 12 % of the total MTOW while using batteries. This slight increase in mass gave a 100 % increase in flight endurance.

The model can be set up for different power requirements that are necessary for a mission. The simulated model gives physical results and based on them there is a possibility to build a real fuel cell stack. Moreover, after a little adjustment, a different kind of fuel cell can be investigated, e.g., direct methanol fuel cell. The model gives an opportunity for optimization of the parameters. There can be optimized any parameter if there will be provided suitable objective function.

Conclusion. A PEM fuel cell was investigated as an alternative solution for battery-based electrical UAVs. The new fully functioning model of the PEM fuel cell was created, optimized, and analyzed. High power and efficient fuel cell achieved, which is better than currently used batteries in the investigated UAV. Flight endurance time was doubled because of the high specific energy of hydrogen. Its high specific energy opens new perspectives for the long endurance of the UAV, with a relatively small increase in mass and volume.

UDC 629.735.33

Starzhynsk A., Ponomarenko S.

TRAJECTORY SYNTHESIS OF THE AEROSPACE SYSTEM DURING SATELLITES LAUNCH INTO ORBIT

Introduction. The development of space technologies has created the prerequisites for the accelerated development of numerous small spacecraft projects with a relatively small investment of time and funds. However, the biggest challenge on the way of expanding the use of small spacecraft continues to be their delivery into space. For many years, the developers have to be guided by the only possibility of the small spacecraft launches as the secondary payloads during large commercial missions. The use of an aerospace system for air launching of small spacecraft appears to be a prospective direction for the development of low-cost and rapid satellite deployment launches.

One of the biggest technical problems during air launch is the unstable state of the launch vehicle. The trajectory and the angle of engines started must be as close as possible to the nominal values. Hence the importance of determining the conditions for synthesis of optimal trajectory for placing the payload into the correct orbit.

Scientific and technical results. The most sensitive part of the flight of the aerospace system, which consists of aircraft carrier (AC) and launch vehicle (LV), is the launch of LV in its target orbit after the separation from the AC. Monitoring of this process is the terminal control task. It lies in placing objects in the given end-state as accurately as possible on the basis of the different target constraints.

The launching trajectory consists of several stages with continuous variable vectors which change within the accepted constrained limits. These shifts often occur at the moments of stage separation, main fairing separation and changes in propulsion engine running condition. To create conditions for performing the operational optimization of branched trajectories were used methods of the theory of optimal complex dynamic systems control. The application of the method consists in representation of a mathematical model of aerospace system motion in the form of a mathematical model of a discontinuous dynamical system.

Necessary and sufficient conditions of discontinuous dynamical system optimal control were defined. Such conditions have adaptability on the perturbations action that cause a change in the parameters of the process of launching into the orbit and provide more accurate execution of terminal conditions at the end of the active launch path.

The research was conducted for the Ukrainian aerospace system project based on the An-124 Ruslan carrier aircraft. Features of design, aerodynamics and operation were taken into account for this reusable system. The optimal trajectory of the launch vehicle during air launch is developed.

Conclusion. Optimization of the launching process allows increasing the efficiency of aerospace systems, to use the maximum possible characteristics and helps to increase the reliability of the flight by increasing the resistance of the output algorithms to perturbing influences.

References:

1. Lysenko A.I. Prospects for the development and application of aerospace launch systems / A.I. Lysenko, S.O. Ponomarenko. – K. : Igor Sikorsky Kyiv Polytechnic Institute, 2019.

2. M.W. van Kesteren. Design and Analysis of an Airborne, solid Propelled, Nanosatellite Launch Vehicle using Multidisciplinary Design Optimization / M.W. van Kesteren, B.T.C. Zandbergen, M.C. Naeije // 6 TH EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUCASS). – 2015. – [Electronic resourc]. – Access mode : https://www.researchgate.net/publication/283056259_Design_and_Analysis_of_an_Airbone_Solid_Propelled_Nanosatellite_Launch_Vehicle_Using_Multidisciplinary_Design_Optimization

3. OM Tachinina Scenario-based approach for control of multi-object dynamic system motion / O.M. Tachinina, I.V. Alekseeva, O.I. Lysenko, S.M. Chumachenko // 2015 IEEE International Conference Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD). – 2015. [Electronic resourc]. – Access mode: https://ieeexplore.ieee.org/abstract/document/7346627

UDC 533.65.013.622:629.735.33

Surkov K., Marynoshenko O.

GENERALIZATION APPROACH FOR AERODYNAMIC COEFFICIENTS CALCULATION DURING UAV SYSTEM IDENTIFICATION

Introduction. Today, the main approach of flight dynamics in general, and system identification of the UAV in particular, is to describe the movement of the UAV as two separate independent movements: longitudinal and lateral. Such an approach is used in order to reduce the amount of interconnections and relations. As a result, not only the complexity of the system is reduced, but also the accuracy of the results is decreasing. When we are considering movements of the UAV, we have to take into account crossing relations between lateral and longitudinal motion that are taking place in real life.

Scientific and technical results. Two of the most important relations that have to be taken into account are yaw and roll angular velocities. These angular velocities cause the change of angle of attack distribution along the wingspan (Fig.1.) and, as a result, - change in total lift produced by wing. This means that we should use some “general” approach during non-theoretical system identification.

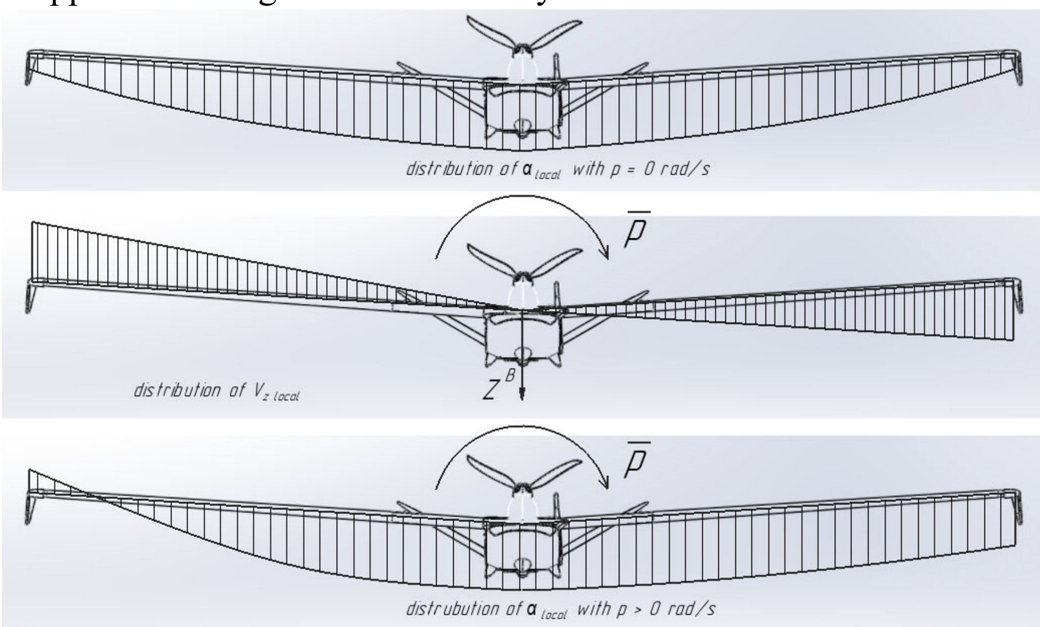


Fig.1. Influence of roll angular velocity on angle of attack distribution.

Usually, the components of lift forces (in wind frame of reference) for longitudinal motion are written as:

$$L = L_{\alpha} + L_{\delta_{elev}} + L_q + L_{\dot{\alpha}} \quad (1.1)$$

or in the form of coefficients:

$$C_L = C_{L\alpha} + C_{L\delta_{elev}} + C_{Lq} + C_{L\dot{\alpha}} \quad (1.2),$$

where $C_{L\alpha} = \frac{dC_L}{d\alpha} \cdot \alpha$, $C_{L\delta_{elev}} = \frac{dC_L}{d\delta_{elev}} \cdot \delta_{elev}$, $C_{Lq} = \frac{dC_L}{dq} \cdot q$ and $C_{L\dot{\alpha}} = \frac{dC_L}{d\dot{\alpha}} \cdot \dot{\alpha}$

The approach of generalization is based on step-by-step calculation of aerodynamic forces and moments using angle of attack and angle of sideslip as to basic values. First of all, upwash angle distribution was calculated. In addition the influence of roll and yaw angular velocities p and r was taken into account in order to calculate true angle of attack distribution along the wingspan. Using angle of attack, the C_L distribution on the wing is calculated for the level flight, and then the corrections for C_L due to aileron deflections were made. This C_L distribution gives us the downwash angle distribution along the leading edge of the horizontal stabilizer. This downwash angle in combination with yaw angular velocity and sideslip angle gives us the angle of attack distribution for the stabilizer that leads us to C_L distribution of the horizontal stabilizer. In addition, C_L of the fuselage was calculated. In result we can find total C_L via equation (1.3).

$$C_L' = C_{Lwing} + C_{LHS} + C_{Lfuselage} \quad (1.3)$$

At this point we should take a look at equations (1.2) and (1.3). If we will think about the nature of all the terms from the right side of the equation (1.2), we will find that C_L' already contains $C_{L\alpha}, C_{L\delta_{elev}}, C_{Lq}$ inside, so the equation (1.2) can be written as:

$$C_L = C_L' + C_{L\dot{\alpha}} \quad (1.4)$$

From (1.4) we can find $C_{L\dot{\alpha}}$ as

$$C_{L\dot{\alpha}} = C_L - C_L' \quad (1.5)$$

The same approach can be used for calculation of coefficients for other aerodynamic forces and moments.

Unfortunately, we are unable to obtain some coefficients, like C_{Lq} with this method, but they can be found using equation (1.2.), because all other coefficients are known.

Conclusion. To sum up all the information mentioned above. This method of generalization gives us the opportunity to take into account most of the crossing relations between different UAV movement components (such as angles, angular velocities, etc.) as well as the interference between different parts of the UAV. In result we can obtain a more complete mathematical model for initial UAV identification.

References:

1. Klein, V. and Morelli, E. A., Aircraft System Identification: Theory and Practice, AIAA, Reston, VA.
2. Yuryev, B.N. Experimental aerodynamics [in 2 parts.]/ Part 2: Theoretical basics of experimental aerodynamics. 1936.

UDC 611.08

Waszkiewicz A., Adamczuk M., Kopyt A.

RESEARCH ON BIOFEEDBACK ANALYSIS AND ADAPTIVE AUTOMATION IMPLEMENTATION FOR HUMAN OPERATOR PERFORMANCE AUGMENTATION

Introduction. Several studies have indicated that both extreme conditions, mental overload and underload, negatively affect task performance as well as the operator's welfare, and need to be mitigated. Mental overload can be associated with excessive stress, frustration, confusion, fatigue and delayed information processing. Performance decrements resulting from the state of mental underload can be associated with loss of situational awareness, insufficient attentional resources and deskilling.Potential solution to this problem could be to design an adaptive system capable of adjusting task difficulty to operator's mental state. The system can maintain the operator's workload within the optimal range.

The development and validation of such a system is the main goal of the presented research. Based on the assessment of operator's functional state the system changes the level of tasks difficulty. Operator's mental workload is evaluated using performance measurement (Performance Index) and engagement assessment (Engagement Index). Two different engagement measurement techniques can be applied, objective and subjective. Objective engagement assessment is based on biofeedback analysis. Having considered pros and cons of various measuring methods we decided to use the following ones: electroencephalography (EEG), heart rate (HR) measurement, galvanic skin response (GSR). Electroencephalography is the measurement of the bioelectrical activity of the brain. Measured signals can be classified into five frequency bands: delta (0,5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), gamma (36-44 Hz). In case when the operator is bored and not involved in the task there is increase in α wave activity and decrease in β and θ wave activity. An increase in α wave activity can be observed when the operator is stressed. Heart rate can be defined as the number of heartbeats per unit time (usually as beats per minute). As workload increases, a person's HR increases. The galvanic skin response is measured by recording the electrical resistance of the skin. This resistance depends on skin hydration. Sweat production increases under human load and decreases the value of human body resistance. Biofeedback measurement station was designed and built (as shown below). It consists of the following equipment: Neurosky Mindwave Mobile 2 (EEG), Neurobit Optima+ 4 (GSR), Polar H10 (HR).

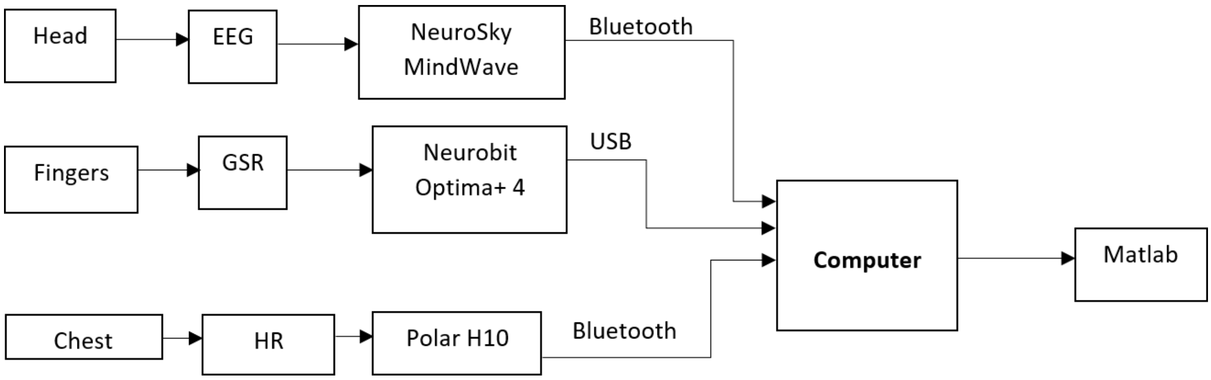


Fig. 1 – Measurement station scheme.

Series of tests were prepared to validate each sensor and to check that the psychophysical parameters do indeed change with the change in cognitive load. The tests were conducted for four participants. Below is an example of a graph for one participant during one of attempts.

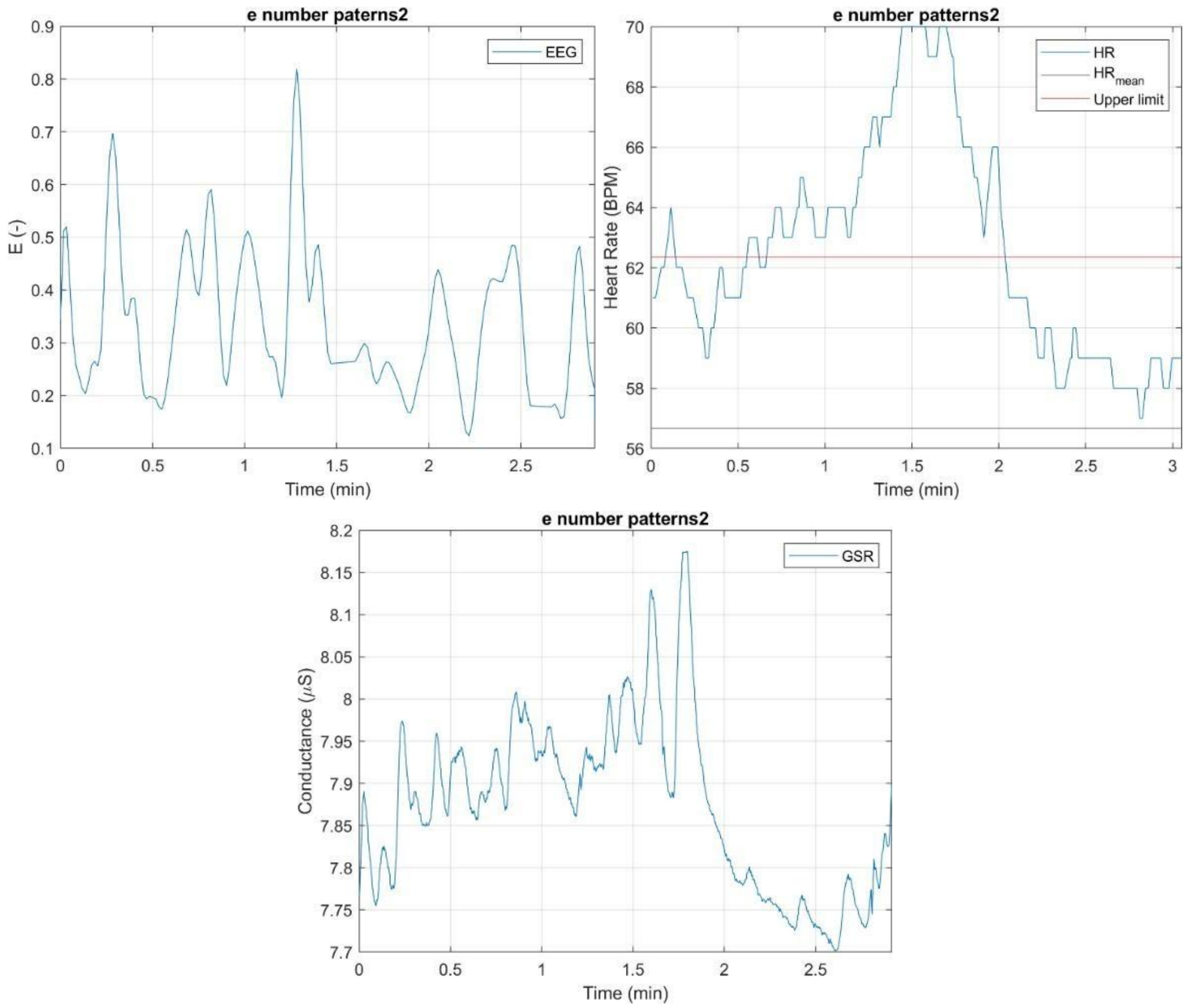


Fig. 2. EEG, HR and GSR results for one participant during second attempt of number patterns task

Scientific and technical results. In all the graphs you can see an increase in cognitive load from around minute 1 and a decrease around minute 2. On the EEG chart this occurs a little earlier before 1 and before 2 minutes. Unfortunately, the results obtained from the EEG measurement are of poor quality and cannot be used for automatic determination of the engagement index. On the other hand, based on the tests performed, it can be concluded that biophysical parameters change with cognitive load and engagement.

The development of the adaptive system was done in parallel with the research exploring the effects of workload on neurophysiological parameters. Since the algorithm to calculate objective Engagement Index based on biofeedback was not developed yet, it was decided that at first the system should use only Performance Index and subjective Engagement Index as input parameters. A simplified version of NASA Task Load Index was implemented to get subjective workload rate. It allows the operator to subjectively estimate the workload along six different categories: mental demand, physical demand, temporal demand, performance, frustration and effort. Considering uncertainty of human behavior, individual differences and ambiguous criteria for the human mental state evaluation it was decided to apply fuzzy modeling for human functional state assessment. Fuzzy logic presents high ability to cope with non-crisp processes and is assumed to be efficient in analyzing human non-linear behavior. Membership functions for inputs (Performance and Engagement – objective and subjective) and for the output (mental workload) were defined and a set of fuzzy rules was created. The adaptive system was implemented in MATLAB/Simulink. In order to determine if it is effective in balancing workload and augmenting task performance, the system was tested during human-in-the-loop experiments. The adaptive aiding was applied in two types of tasks, Multi-Attribute Task Battery II (MATB-II) and a tracking task. MATB-II is a computer based multitasking environment designed by the NASA for the research on human mental workload and performance. It consists of four tasks that are supposed to be similar to activities that crew members need to perform in flight – system monitoring, communications, tracking and resource management. Additionally, a simple tracking task was created in Simulink. While executing this task the operator is asked to follow the signal appearing on the screen using a joystick. For both task sets, MATB-II and tracking, three different difficulty levels were defined and a method to measure Performance Index was developed. During human-in-the-loop experiments the participants were first asked to perform the tasks on easy and then on difficult level. Next, they were executing the same tasks but the task difficulty was being adjusted by the system every 60 s. In case of MATB-II performance score improved compared to difficult task conditions.

Conclusion. Experiment results indicate that the system is capable of successfully adapting task difficulty to the operator’s state and is efficient in maintaining the operator’s workload within optimal range.

References:

1. R. Zhu, D. Sun, Z. Zhou, and D. Wang, “A linear fusion algorithm for attitude determination using low cost mems-based sensors,” Measurement, vol. 40, no. 3, pp. 322–328, 2007.

2. R. Munguia and A. Grau, “Attitude and heading system based on ekf total state configuration,” in 2011 IEEE International Symposium on Industrial Electronics. IEEE, 2011, pp. 2147–2152.

3. J. L. Crassidis and F. L. Markley, “Unscented filtering for spacecraft attitude estimation,” Journal of guidance, control, and dynamics, vol. 26, no. 4, pp. 536–542, 2003.

UDC 629.7.023

Zakharchenko M., Arkhypov O.

CHOICE OF MATERIALS FOR FUEL TANKS OF THE LAUNCH VEHICLE WITH LIQUID ROCKET ENGINE

Introduction. The mechanical properties of the fuel tank (FT) design for launch vehicle (LV) have been studied in the work depending on the materials and combinations of materials from which it is built.

FT are designed to accommodate fuel components and supply them to the engine unit and for the perception and transmission of loads.

FT are the main part of the design of a liquid rocket and determine its dimensions and mass characteristics [1]. The choice of construction material is fundamental in the process of designing FT housings [2]. Aluminum and titanium alloys and composite materials (CM) can be considered in the first place.

Formulation of the problem: The goal of this work is to study the influence of different materials and their combinations on the weight characteristics and strength for liquid fuel rocket engines (LFRE).

Scientific and technical results. The design of FT from the wall and power frame is considered in the study for each material and their combinations. Materials AMg6, D16 and composite material with reinforcing carbon fabric and their combinations were selected for the study.

Requirements for fuel tanks:

- minimum weight at a given bearing capacity;
- tightness and corrosion resistance;
- reliability of operation in the process of ground operation
- simplicity and manufacturability of a design

The calculation of geometric parameters was performed in the software environment Matlab 2019.

The optimization algorithm is built according to the chosen method [3] on the principle of ensuring the discrete uniformity of individual substructures.

An example of a structure consisting of composite sandwich panels and an aluminum core is given in the study [4]. This structure is designed to reduce the structural mass and improve the static and dynamic structural rigidity of the structure

The research process can be divided into the following stages: determination of geometrical parameters of the tank for each material, calculation of the weight of the structure, calculation of strength, analysis of the results.

The tank model for each material was built according to the obtained tank parameters in the SolidWorks 2016 software environment and the weight of each structure was determined.

Strength calculations are performed in the SOLIDWORKS Simulation application.

Conclusions. The scheme in which the wall and the power set are made of CM, and the inner wall of AMg6 is the most optimal for the LV tank with the specified parameters. Significant weight savings of 12.7 kg (23.6%) are the advantages of this solution compared to the design with AMg6.

References:

1. Bliznichenko VV, Dzhur EO, Krasnikova RD, Kuchma LD, Linnik AK and other; Konyukhova SM editor. Design and construction of launch vehicles: Textbook. DNU Publishing House, 2007. - 504p.

2. Solidification Alicia Esther Ares / BoD – Books on Demand, 14 бер. 2018 р. - 162 стор.

3. DEHTIAROV, Maksym O., et al. Methods to Reduce Material Intensity of Tail Sections of Launch Vehicles. Journal of Mechanical Engineering, 2020, 23.3: 27-36.

4. Kim, Byoung Jung. "Development of a satellite structure with the sandwich T-joint." Composite Structures 92.2 (2010): 460-468.