1ST INTERNATIONAL AEROSPACE SYMPOSIUM
THE SILK ROAD

BOOK OF ABSTRACTS

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Modeling for Space Applications

"Water pump" mechanism of transporting vapor to the Martian upper atmosphere

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Keywords: Mars, modelling, hydrological cycle, water pump, upper atmosphere, dust storm

Recent studies link the observed hydrogen escape in the thermosphere of Mars to the water of lower atmospheric origin. However, the cold mesosphere hinders penetration of water vapor into the upper atmosphere. We present results of simulations with a general circulation model developed at Max Planck Institute for Solar System Research (MPI-MGCM) that implements a state-of-the-art hydrological cycle scheme. The simulations reveal the “water pump” mechanism responsible for the upward transport of vapor. It takes place in high latitudes of the southern hemisphere during summers, when the upward branch of the meridional circulation is particularly strong. We demonstrate that a combination of the mean vertical motions with the periodically varying flux due to solar tides facilitate water vapor leakage across the “bottleneck” located at approximately 80 km. The meridional circulation then transports water across the globe to the northern hemisphere. Since the intensity of the meridional cell is strongly controlled by airborne dust, the amount of water in the thermosphere critically depends on the dust scenario. In our simulations for non-dusty years, this mechanism provides a few tens of ppmv of water vapor above 100 km. We will present also simulations for the Martian Year 28 global dust storm and compare with the Mars Climate Sounder observations.

Non-hydrostatic general circulation model of the Venus atmosphere

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Keywords: Venus atmosphere, general circulation model, fluid dynamics, Venera-D

We introduce some results obtained from numerical simulations of the global circulation of the atmosphere of Venus in the framework of the complete set of gas dynamics equations1,2. We shall note that this is the joint development of Moscow Institute of Physics and Technology and Polar Geophysical Institute. In the model the atmospheric gas is considered as a mixture of gases of constant composition, and the aerosol component of the atmosphere is ignored. The region of simulations extends from the surface to an altitude of 120 km above an average level of the surface. In the present analysis, we used a uniformly spaced grid in spherical coordinates with 256 and 128 nodes in longitude and latitude (the step is 1.40625°), respectively, and 481 nodes in altitude (the step is 250 m).

The model allows simulating variety of mesoscale processes in the top layers of Venus atmosphere. For example, it was shown that in the polar regions of Venus there are vortices with a characteristic scale of changes in the wind velocity of about 300 km. Energy balance in the model is implemented with the help of the simplest relaxation approximation. In the future model development, realistic simulation of the radiation transfer is to be added.

The latitudinal structure of the clouds is considered, and two mid-latitude and one equatorial jet can be observed. Indeed, it is obtained through the analogous phenomenon so-called submerged jet, which is not so widespread in geophysics. The

results obtained are compared to the earlier publications received from simulations with the use of hydrostatic model. Also we need to note that the current version of the model is employed for the preparation of the Russian-American joint space mission “Venera-D”.

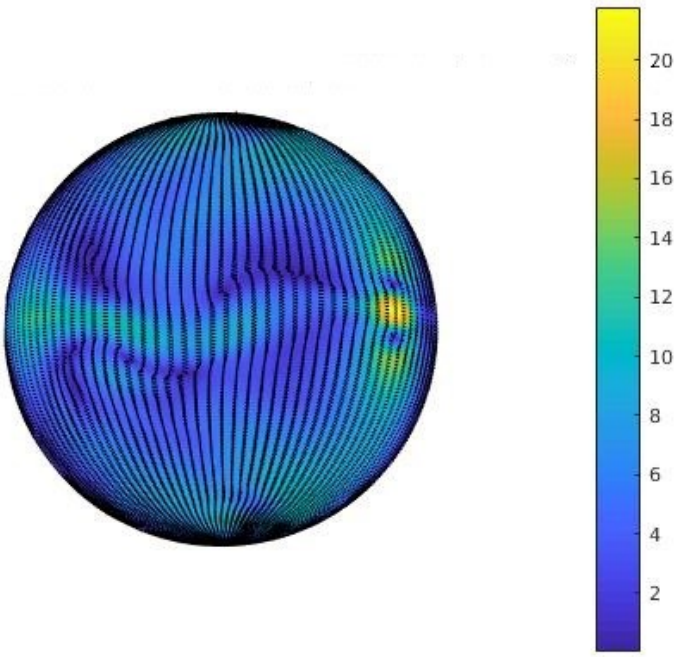

Fig. 1

References

1. Mingalev I.V., Rodin A.V, Orlov K.G., A Nonhydrostatic Model of the Global Circulation

of the Atmosphere of Venus, Solar System Research, 2012.

2. Mingalev I.V., Rodin A.V, Orlov K.G., Numerical Simulations of the Global Circulation of the Atmosphere of Venus: Effects of Surface Relief and Solar Radiation Heating, Solar System Research, 2015.

Feature-Based Deep Learning Method for fluid dynamics

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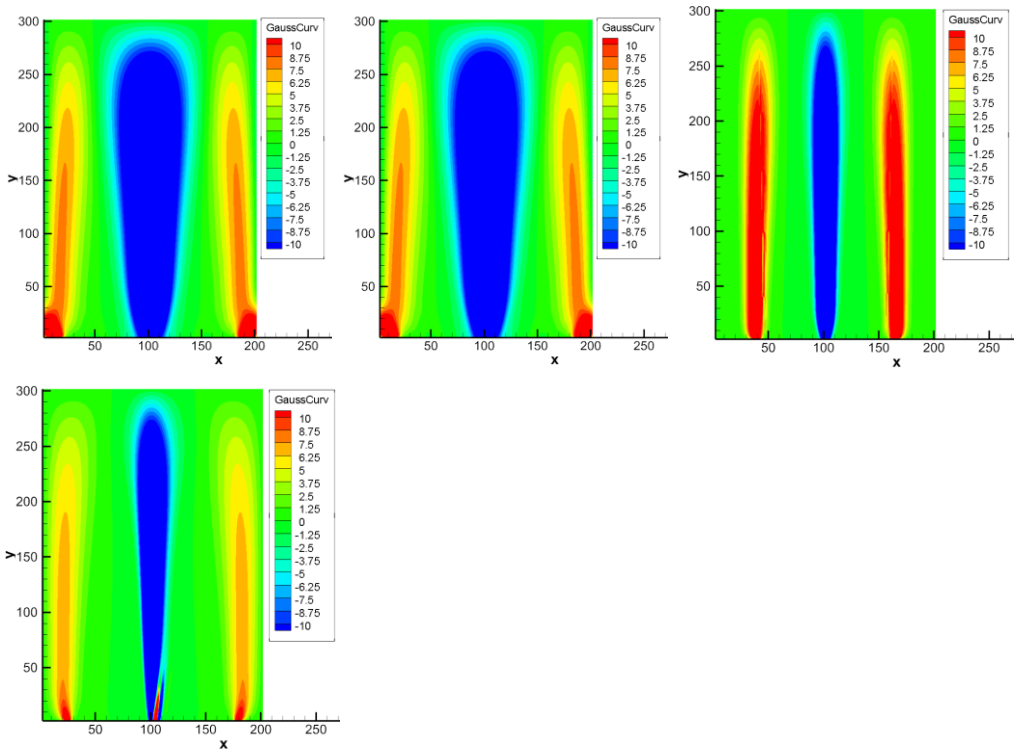
Keywords: Deep Learning, Convolutional Neural Network, Machine Learning, Computational Fluid Dynamics, Reduced Order Model

A feature-based Deep Learning technique to capture characteristics of fluid system and predict forces is carried out in this paper. Although NN (Neural Network) is an efficient model for reducing order of fluid system, traditional NN models are actually simple numeric fittings between input and output and failed to reflect the inherent characteristics of physical systems. Different from these, we use a novel DNN (Deep Neural Network) method to improve the accuracy and generalization capability through adopting convolutional neural network to extract the specially processed disturbance information of boundary in flow field. Through deep learning process, parameters of the network will be ascertained. Using 2D model, the DNN is fed by the specially processed curvature of flow field grid as the input and the aerodynamic forces computed by the full order CFD (Computational Fluid Dynamics) simulation as the target data. After the DNN is iteratively trained, the predicted results on new samples show good consistence with the full-order computations. The proposed feature-based Deep Learning technique has an important and wide significance to the design and control of aircraft, especially when the problem of computational resources of full order simulation is prominent.



a) ration=3 b) ratio=5 c) ratio=10

Fig. 1 The contour of curvature of grid lines caused by ellipses with different aspect ratio

References

1. J.N. Kutz, Deep learning in fluid dynamics, Journal of Fluid Mechanics, 814 (2017) 1-4.

2. I. Goodfellow, Y. Bengio, A. Courville, Y. Bengio, Deep learning, MIT press Cambridge, 2016.

3. T.P. Miyanawala, R.K.Jaiman,An Efficient Deep Learning Technique for the Navier-Stokes Equations: Application to Unsteady Wake Flow Dynamics, (2017).

4. S. Lee,D. You, Prediction of laminar vortex shedding over a cylinder using deep learning, arXiv preprint arXiv:1712.07854, (2017).

5. Z. Wang, D. Xiao, F. Fang, R. Govindan, C. Pain, Y. Guo, Model identification of reduced order fluid dynamics systems using deep learning, International Journal for Numerical Methods in Fluids, 86 (2018) 255-268.

6. Y. Zhang, W.J. Sung, D.N. Mavris, Application of Convolutional Neural Network to Predict Airfoil Lift Coefficient, in: 2018 AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2018, pp. 1903.

Design and development of spacecraft structures in terms of ensuring their maximum strength and minimum weight

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Keywords: shape memory alloys, sea-based space transportation system, bio-similar movements, static and dynamic strength

Spacecrafts are very complex type of structures, which require expanding the search field for new design solutions, reducing strength margins, combining materials with new properties, including self-tuning to flight mode, as well as refined computational methods. The results of a number of studies of experimental aircrafts are presented, in which an important role is played by reducing the proportion of the relative weight of the structure in take-off weight of the aircraft, as well as ensuring its static and dynamic strength in all design cases of loading.

The current state of design, the availability of materials with unconventional properties, such as shape memory alloys, and the possibility of mathematical and natural modeling, lead to the emergence of new technical solutions. So, it is possible to change the shape and properties of the structural material, changing the geometric shape of the object and other properties. In a number of cases, substructures with curvilinear elastic axes become optimal.

The reusable sea-based space transportation system based on the orbital space flight showed the layout and strengths of the closed wing contour. Studies on specially designed synthesis programs made it possible to determine the rational form of the elastic axis of the wing of the aircraft, reducing its force weight by 15-20%.

The direction associated with the use of structural materials with different characteristics in spacecrafts, currently a section of exploring shape memory alloys, both in the form of elements with a variable elastic modulus, and as a function of actuators of movements and deformations. In TsAGI, a study was conducted that showed the effectiveness of self-tuning of the air intake of an aircraft depending on the flight mode of an aircraft, associated with a change in the shape of the active elements as a result of aerodynamic heating. a stand has been created at the MIPT (FALT), which allows to simulate the operation of the aircraft keel's torsion drive based on the shape memory alloys jet forces. The approaches to the problem of technical implementation of bio-similar movements and transformations of structures are investigated.

Experimental and Numerical Investigation of Tip Vortex Structures on a Bio-inspired Discrete Wing

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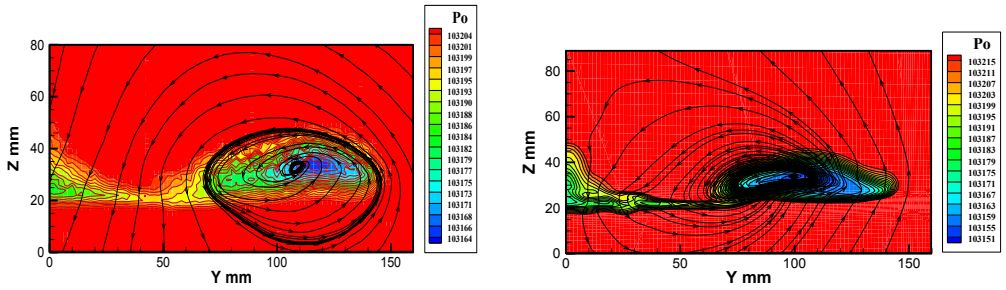
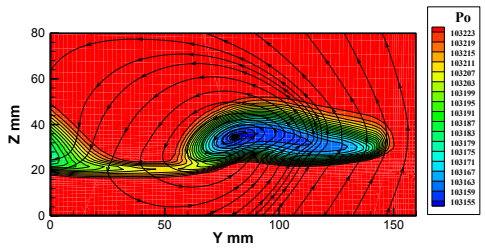
Keywords: bio-inspired discrete wing structure, numerical simulations, wind tunnel tests, total vorticity distribution, wing-tip vortex strength

In nature, birds have gone through thousands of years of biological evolution, eventually forming a unique wing structure suitable for their living environments. Even in dense jungle or urban environments, birds can accomplish rapid adjustment of wing postures to meet various mission profiles. A bird wing is composed of a morphing skeleton structure covered with numerous flexible feathers partially overlap each other. Besides the morphing skeleton structure which can cause large-scale wing geometric changes, the unique discrete wing surface structure similar to a staircase structure can also play an important role in improving aerodynamic performances of birds. In this study, a bio-inspired discrete wing structure inspired from a fully-extended pigeon's wing structure was specifically designed with the aim of validating the aerodynamic advantages of the discrete wing structure from the aspect of tip-vortex structures when compared with a continuous smooth wing surface. The experimental models are as follows: 1. A bio-inspired discrete wing; 2. A continuous smooth wing. It is hard to guarantee numerical calculation accuracy for the complicated discrete wing structure. Thus, numerical simulations were carried out only for the continuous smooth wing using two different turbulence models (SST model and S-A model), in order to obtain a direct comparison between numerical and experimental results for the continuous smooth wing. The wind tunnel tests were carried out in a straight-flow wind tunnel using a seven-hole pressure probe system (angular resolution of 0.2 degrees and a speed measurement error

range of +1%). The tip-vortex measurements were made at a certain rectangular YZ plane (the value of x/c determines location of the YZ plane; x represents the distance between the leading edge of a wing model and a certain measuring point; c denotes a chord length of a wing model) for different attack angles. There are some key results in this study. Fig. 1 shows that a direct comparison between experimental and numerical results of the continuous smooth wing. It can be seen that the experimental result basically coincides with the numerical results simulated with two different turbulence models. Fig. 2 shows that the bio-inspired discrete wing has much smaller total vorticity when compared with the continuous smooth wing at the downstream region of x/c=1.2 for α=8 deg. The bio-inspired discrete wing structure can effectively reduce the wing-tip vortex strength.

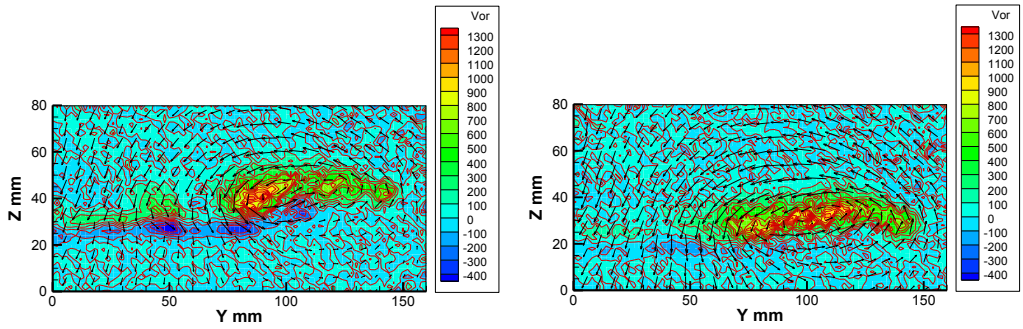


a) EXP b) CFD using SST model



c) CFD using S-A model

Fig. 1 Numerical and experimental comparisons on two-dimensional total pressure distributions of the continuous smooth wing at the downstream region of x/c=1,2 for α=8 deg



a) A bio-inspired discrete wing b) A continuous smooth wing

Fig. 2 Two-dimensional vorticity distributions of two different wing surface structures at the downstream region of x/c=1,2 for α=8 deg

References

1. Lentink D, Müller U K, Stamhuis E J, et al. How swifts control their glide performance with morphing wings[J]. Nature, 2007, 446(7139): 1082.

2. Di Luca M, Mintchev S, Heitz G, et al. Bioinspired morphing wings for extended flight envelope and roll control of small drones[J]. Interface Focus, 2017, 7(1): 20160092.

3. Sachs G, Holzapfel F. Flight mechanic and aerodynamic aspects of extremely large dihedral in birds[C]//45th AIAA Aerospace Sciences Meeting and Exhibit. 2007: 46.

4. Thomas A L R, Taylor G K. Animal flight dynamics I. Stability in gliding flight[J]. Journal of Theoretical Biology, 2001, 212(3): 399-424.

Structure and shear coupled motion of <001> tilt grain boundaries in titanium nitride

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Keywords: Titanium nitride; Grain boundary; Shear-coupling; Dislocation; Vacancy

Titanium nitride (TiN) is widely used as hard coating due to its wear-resistance, high hardness and chemical inertness. Thus, the design and development of hard coatings require a better understanding of the mechanical response of TiN. Shear deformation mechanisms of TiN grain boundaries (GBs) govern many aspects of TiN performance. To unveil the underlying deformation mechanism in polyscrystalline and nanocrystalline TiN, a deep knowledge of structure and mechanical behavior of TiN GBs is required. In this work, we attempt explore the temperature on the shear deformation mechanism in TiN GBs. The structure and shear response of TiN GBs are studied for a wide range of TiN <001> tilt GBs using molecular dynamics. By utilizing the rigid body translation (RBT) and atoms removal method, a serious of equilibrated GB structures at 0K are obtained. We find that the equilibrated GBs at 0K only contain kite-shaped structures connected with some edge dislocation cores. The equilibrated GBs are sheared at 300K and 800K using the canonical ensemble with Nosé-Hoover thermostat. A thorough analysis of shear response of all these GBs shows that there exist five deformation modes. First two modes correspond to the GB sliding, but they differ whether fracture or atom shuffling occurs during GB sliding. Other three modes are all related to the shear deformation coupled with GB migration.. Based on the geometrical analysis of GB deformation, we develop two modified shear-coupling factors, by which two

imperfect shear-coupling can be well described. Fig.1 illustrates the geometrical analysis of GB Σ17(350). Fig.2 compares the calculated and predicted u// for three GBs. Further, we examine how the multiple GB states effects the coupled motion for a fixed tilt angle by introducing vacancies to GB plane.

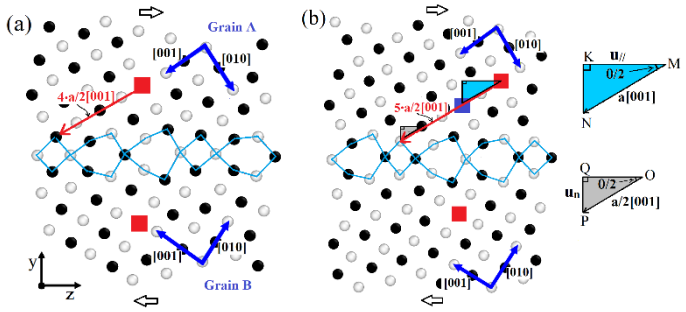

Fig. 1 A complete structure transformation of GB Σ17(350). (a) and (b) correspond to Figs.15a and 15c. Ti and N atoms are colored in black and grey, respectively. Here and in Fig.21, red arrows are used to measure the growth of grain A in the [001] direction, and some atoms marked by small filled squares are used to monitor relatively sliding between two grains. *Δ*MNK and *Δ*OPQ correspond to two blue and grey triangles in the bicrystal in (b). KM of *Δ* MNK in (b) is the total relative sliding of two grains due to GB motion and GB sliding. PQ of *Δ*OPQ is un and QO of this triangle represents part of u// due to GB motion

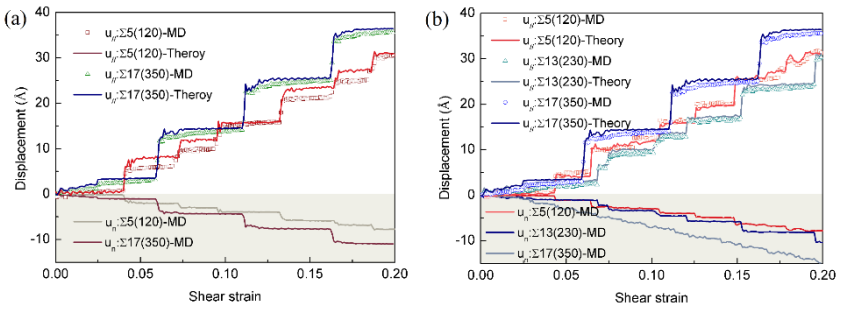

Fig. 2 A comparison of calculated and predicted u// for three GBs at (a) 300K and (b)800K. Note that data is absent for Σ13(230) GB at 300K since its deformation mode is sliding-fracture

Regolith of Near-Earth Asteroids (NEA) as the target of satellite mission: Itokawa' lesson

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Keywords: asteroids, regolith, remote sensing, satellite, meteorites

Regolith on C- and S-type asteroids is an impact-treated surface layer, containing rest of the meteorites, too. The increased content of rare and valuable elements makes the analysis of this layer an important scientific and practical task of a future satellite mission. Now, we have a variety data concerning dust particles delivered by the Hayabusa spacecraft from the surface of near-Earth asteroid 25143 (Itokawa). It concerns chemical, mineral, isotope and a number of other analyses provided from japans' scientists, mainly. It turned out that Itokawa dust particles are identical to thermally metamorphosed LL chondrites and connect theirs with S-type asteroids. From the other side, GEOKHI scientists have identified and characterized the major, minor and trace mineral phases in rock chips and dust of the Chelyabinsk meteorite, fall 15 February 2013, over Chelyabinsk, Russia [1]. Raman spectra were shown for olivine, pyroxene, feldspar, pyrrhotite (Fe sulfide group), oxides Fe-Ni metals, carbonates and phosphates [2].

A number of analyses provided full information on compositional variations of the above minerals and modal proportions of the rock which identify Chelyabinsk meteorite as LL5 S4 W0 ordinary chondrite. So, we have a minimally contaminated material, which can be used for the analysis of the possible relations between Itokawa and parent body of the Chelyabinsk meteorite. As typical NEA objects, they present interesting scientific opportunities both for direct geochemical and astronomical investigation of LL chondrites genesis and dynamical evolution. W. F. Bottke with collaborators created a steady state model of the orbital and absolute magnitude distribution of the NEA population, which connects with the dynamics

of Main Belt Asteroids (MBA) [3]. Thus, the NEA study provides valuable scientific and practical information on the composition, structure and dynamic evolution of the MBA as whole.

Acknowledgment: This work was supported by the grant Program 28 of Presidium RAS, coordinators ac. Zeleny L.M. and Marov M.Ya.

References

1. S. A.Voropaev et al. Geochemistry International 51(7): 593-598, 2013.
2. E. M. Galimov et al. Geochemistry International 51(7): 522-539, 2013.
3. W. F. Boettke et al. Icarus 156: 339-433, 2000.
4. P. Michel, M. Yoshikawa. Astronomy &Astrophysics 449: 817-820, 2006.

Perspective instrument Meteor-2 for study and collection of samples from asteroid transit atmosphere

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Keywords: asteroids, satellite, meteorites, transit atmosphere, sample delivery

The basic scientific instrument “Meteor” is dedicated for study of meteor matter distribution in space and for obtaining the data on physical and dynamical parameters and composition of individual high-velocity particles. The instrument “Meteor” allows determination of velocity, mass and composition of falling particle by properties of plasma formed during its collision with detector surface on path to space body and also at its orbit.

“Meteor 2”, a perspective modification of this device besides studying meteor particles flow on the path to space body will allow us to collect particles of asteroid regolith and return it to the Earth. Collected and delivered to the Earth samples are of significant interest for studying in laboratories.

The meteorite experiments that use apparatus of ionization type on interplanetary stations to study space bodies such as asteroids and comets are of great interest. Latest missions, such as Rossetta, Hayabusa and others, showed uneven distribution of meteor matter in space. In proximity of large space bodies that are attractors, meteor particles form dust shells with different density, structure and size.

Any impact of meteoroid or man-made projectile on atmosphereless body with low gravity generates dust cloud or so called transit atmosphere. During collision of 1 to 10 kg meteoroid body with an asteroid, formed plum may be up to several hundred km in size.

Particles discarded from the impact will have intense interaction with solar wind and may be positively or negatively charged depending on their mineral composition. Such particles can be collected by instrument “Meteor 2” due to its specialized design. In order to avoid contamination of collected regolith particles they will be preserved in impermeable reservoir after ending of exposition time up until its return to the Earth.

Acknowledgment: This work was supported by the grant Program 28 of Presidium RAS, coordinators ac. Zeleny L.M. and Marov M.Ya.

Near-Earth Asteroids as a Base for Interplanetary Economy Supply

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Keywords: asteroid mining, space logistics, supply-chain network, interplanetary economy

Near-Earth Asteroids (NEAs) are frequently considered as a source of water and precious metals for Earth's needs [1]. The reason is a relatively small delta-v to perform outbound and return transfers from Earth to a NEA and variety of minerals presence on asteroids. However, techno-economic analysis of asteroid mining in application to the Earth supply shows that a number of technologies has to be developed. Moreover, high production rate should be reached to make an asteroid mining feasible for Earth-based supplies [2]. In this work, asteroid mining is considered for Mars colonies supply. In-situ resource utilization (ISRU) on Mars can support most of colony needs. However, a variety of materials and its number are limited on Mars. In order to enable fuel generation, production of building materials additional resources have to be brought. Thus, the work shows the comparison of two different Mars supply approaches. The first one is direct supply of the Mars colony by Earth's resources. The second one is colony supply by extra-terrestrial resources utilized from small Solar System bodies like asteroids or comets. We propose to consider a network economy that includes Near-Earth Asteroids (NEA) and Earth as a source of minerals and Mars as place with demands (see Fig. 1).

The work consists of three main parts. Firstly, asteroids selection problems is studied. We consider 20 years duration Mars supply mission starting from January 1, 2050. Cargo spacecraft with payload mass of one tone and maximum delta-v capability of 6.0 km/s is considered for materials transporting between nodes of a network. Based on the mission parameters requirements for target asteroids are

specified. JPL Small-Body Database Search Engine [3] together with simplified delta-v calculation [4] are used to get the list of NEAs that satisfy requirements. The second part of the work is devoted to the calculation of flight opportunities for Mars colony supply. To calculate the flight opportunities a set of orbital elements are specified, corresponding to bodies in strictly heliocentric orbits. For each mining site delta-v maps are created for the transfers to and from Mars.

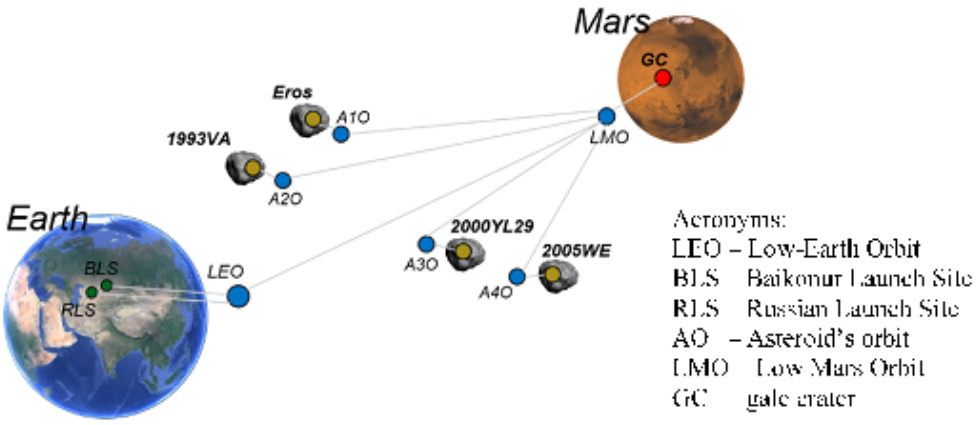

Fig. 1 Interplanetary network model

Finally, from each delta-v map for outbound and return Mars supply transfers, a list is compiled of local minimums below a maximum dV capability of the spacecraft. In the third part, comparison of different supply approaches is provided. The work shows that there are thresholds that can limit colony sizes due to the limited amount of cargo delivered from the Earth through the campaign. Thus, using ISRU on NEAs help to support bigger colonies with bigger needs.

References:

1. Andreas M. Hein et al. 'Exploring Potential Environmental Benefits of Asteroid Mining'. 69th International Astronautical Congress (IAC), 2018.

2. Andreas M. Hein et al. 'A Techno-Economic Analysis of Asteroid Mining'. 69th International Astronautical Congress (IAC), 2018.

3. JPL Small Body Database Search Engine, https://ssd.jpl.nasa.gov/sbdb_query.cgi, (accessed 10.09.2018);

4. Shoemaker, E. M., and E. F. Helin. "Earth-approaching asteroids as targets for exploration." (1978).

An adaptive algorithm for search and support of the equilibrium orbital orientation of the International Space Station

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The dynamics of controlled angular motion of the International Space Station (ISS) in the mode of autonomous search and maintaining its equilibrium orientation relative to the orbital basis is considered. The equilibrium position is determined by zeroing the superposition of the gravitational, aerodynamic, and gyroscopic torques. The description and the analysis of functioning of the adaptive algorithm of iterative search of an equilibrium position integrated into the on-board software of the ISS control and navigation system (ISSN) is given. Calculations are presented for the search for optimal pulse values on the steady (limiting) self-oscillating cycle of the relay control system, the width of its dead zone and the quaternion of the turn from the orbital basis to the equilibrium position, which ensure a minimum fuel consumption for a given time interval. The efficiency of the algorithm is illustrated by the results of mathematical modeling and full-scale tests.

Application of algorithm of sequence-closure in the problem of searching and maintaining the equilibrium orientation of the large space station

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The report deals with the angular motion of a Large Orbital Station (LOS). The dynamics of the LOS is described by a linearized system of equations obtained by applying the theorem on the change of the kinetic moment separately to the station body and separately to the rotating elements of the structure. To this are added the equations describing the aerodynamics. In this problem, it's the first 3 tones of the decomposition in Fourier series of functions of the atmospheric density at the coil, which are presented in the form of oscillators. The control of the CSC orientation along gyroscopically connected channels of roll and yaw and separately along the pitch channel is considered separately. A numerical algorithm of modal synthesis based on the algorithm of sequence-closure of modes is used to construct the law of control of the LOS orientation. As a reference polynomial, generalized Butterworth polynomials are used to construct the control law. This reference polynomial was chosen to provide a high degree of stability of the synthesized control system, as well as a low degree of oscillation.

Method of Development Testing the Visual Navigation and Hazard Detection System Designed Based on Unified Functional Modules

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Joint Stock Company "Russian Space Systems"

Nowadays a large number of research missions to study space bodies in the Solar System with landing of the spacecraft is studied. The visual navigation and hazard detection system (VNHDS) intended to form navigation information and development of the decision on safety of the underlying surface has to be a part of the systems of the landing module. VNHDS is in fact a model of a control system of any spacecraft and a representation of a difficult hardware and software system and control of the process, the development of which has to be carried out according to the principles of system engineering. System engineering is a complex methodology, which is responsible for creation and performance of various efforts necessary for meeting all requirements imposed on VNHDS. The fundamental of the methodology is the V-model of a life cycle of any hardware and software system.

In this regard, a control system of spacecraft is exposed to a large number of ground tests on which the quality of the received product depends. One of the types of such tests are functional tests at the complex stand, which assume development of software functioning together with the product equipment in real time. With the growth of complexity and volumes of the tasks realized in control systems of spacecraft, volumes, duration, and labor intensity of the tests directed to confirmations of the system operability increase.

The unified functional modules received on the previous projects of product development can be employed in new systems with the reduced volume of tests: such module does not demand adjustment of hardware-software interaction. Hence, to receive a spacecraft control system it is enough to assemble the available modules in a new configuration and to download a corresponding software for their interaction. New modules are developed to solve the tasks of spacecraft in addition to the available ones. In this case, only new modules are adjusted to the full extent

and the tests confirming a correct functioning of a control system in general, which main volume is realized out at PMSS, are carried out.

The given approach of functional ground tests of spacecraft control systems developed based on unified functional modules considers the advanced international experience of creating complex control systems applying a system engineering method and makes it possible:

- to effectively carry out debugging and adjustment of functioning of a new spacecraft control system;
- to carry out tests of the software of functional modules and a system in general in parallel with development of the hardware;
- to use the same complex stand for control systems with various configurations of modules.

References

1. Kosyakov A., Sweet W.N., Seymour S.J., Biemer S.M. Sistemnaya inzheneriya. Printsipy i praktika [Systems Engineering: Principles and Practice]. Moscow, DMK Press, 2014. (in Russian)

2. Jones D., McKay B. Model'no-oriyentirovannoye proyektirovaniye sistem upravleniya: modelirovaniye i testirovaniye do realizatsii v apparature [Model-based design of control systems: modeling and testing until implementation in the equipment]. Control Engineering Russia, 2013, #4 (46), pp. 50–52. (in Russian) (translated from English by Orlov Yu.)

3. Mikrin E.A. Bortovyye kompleksy upravleniya kosmicheskimi apparatami i proyektirovaniye ikh programmnogo obespecheniya [Onboard spacecraft control complexes and designing of their software]. Izdatel'stvo MGTU im. N.E. Baumana, 2003, 336 p. (in Russian)

4. Zharikov V.N., Pichkalev A.V. Problemy otrabotki programmnogo obespecheniya bortovoy radioelektronnoy apparatury [Problems of optimization of software of on-board radio-electronic equipment]. Vestnik of SibGAU, 2012, No. 1 (41), pp. 16–17. (in Russian)

5. Trifonov O.V., Yaroshevskiy V.S. Stend dlya otladki bortovogo programmnogo obespecheniya kosmicheskogo apparata [The stand for debugging on-board software of spacecraft]. Working paper of the Keldysh Institute of Applied Mathematics, 2018, No. 106, 12 p. (in Russian)

About illumination of Russian Arctic regions by groups of satellite illuminators with total reflected sunlight during the polar night

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This project is dedicated to solving the problem of insufficient lighting of Arctic regions in Russia and abroad during the polar night using large area reflectors placed on the orbit of Earth.

We developed an algorithm to manage orbital parameters of sun-synchronous orbits by using only force of radiation pressure which influences the reflector. The method allows to control and adjust values of parameters. Using radiation pressure power as we suggest would reduce the amount of rocket fuel needed which is highly expensive in cost and limited in possible ammunition that a spaceship can take. Therefore, this increases exploitation period of apparatus.

We also concluded that chosen size of a sun-sail is not sufficient for regular changing of orbit's parameters. However, it allows correcting their values when slow pace of orbit's changing is sufficient.

Flexoelectricity and its applications energy harvesting

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Recently, a somewhat understudied electromechanical coupling, flexoelectricity, has attracted a fair amount of attention from both fundamental and applications points of view leading to intensive experimental and theoretical work. Piezoelectricity is restricted to only certain crystal structures and refers to a linear coupling between the development of polarization due to the action of uniform deformation and vice versa. In contrast, flexoelectricity links strain gradients to polarization and, in principle, exists in all dielectrics. In other words, even in non-piezoelectric materials, strain gradients can lead to the development of polarization. This effect is generally small, but symmetry allows for its universal presence unlike piezoelectricity. Since strain gradient scales with feature size, and high values are easily obtainable at small length scales, flexoelectricity is expected to be significant at the micro and nanoscale possibly outperforming piezoelectricity in several scenarios.

In this talk, the flexoelectric effect in solid dielectrics is briefly introduced. The mechanism unpinning this phenomenon is also discussed in detail. A new methodology of measuring flexoelectric coefficients through wave propagation in solids is pro-posed and experimentally validated. At last, the idea of employing flexoelectricity for vibrational energy harvesting is introduced. Different from piezoelectricity, flexoelectricity is a universal electromechanical coupling which scales with the size of the sys-tem. At nanoscale, the effect of flexoelectricity may dominate the electromechanical behaviors of a piezoelectric material. Based on this idea, we examine in detail, the possibility of using the phenomenon of flexoelectricity for energy harvesting especially at nanoscale. Our theoretical work shows that the conversion efficiency of a de-signed flexoelectric energy harvester increases drastically as the decrease of system size at submicron or nanoscale.

Flexoelectric energy harvesting with circular membrane

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Keywords: Energy harvesting, flexoelectricity, vibration

With the development of micro electro mechanical system, how to supply enough electric energy to the micro equipment is attracted extensive attention worldwide. Nowadays, piezoelectric material is used to build these kinds of device, but the limitations of piezoelectric material is as obvious as its advantages. There are two key limitations which are the high frequency work bend and low energy transfer efficiency. For my recent work, the flexoelectric effect is considered to use to gather energy. The flecoelectricity is an effect which induce the polarization by the strain gradient. This effect is related to the size effect which means that the device can be micromation. A linear flexoelectric energy harvesting device with circular membrane is designed.

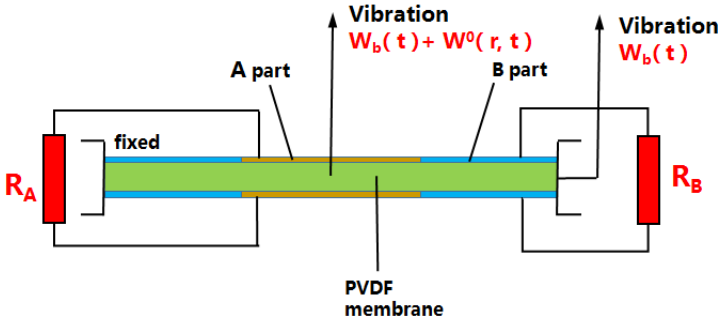

Fig. 1

Liked the figure 1 showed, the isotropic PVDF material is used to harvest energy, the model is described using cylindrical coordinates, the electrodes are divided into two parts, and the membrane is Circumferential fixed. The membrane will vibrate with the fixture, and have a relative vibration between the fixture. Caused the relative vibration of membrane and fixture, the two parts of the PVDF membrane will have the opposite polarization direction, and the current will flow through RA and RB. The Kirrchoff-Love plate theory is used to describe the model,

and one of the governing equation is derived by the energy equations, the other two governing equations are derived by the Ohm's law. By dividing the membrane into two parts and inserting the corresponding resistances, the energy transfer efficiency enhance more than two orders of magnitude, and the highest efficiency is more than 10%. Using the designed model, through exchange the shape, thickness, boundary of the membrane, we found that the output of power density and the conversion efficiency are closely related to the thickness of the membrane, and the shape and boundary also influence the output. When the thickness of the membrane is on the order of micrometers, the efficiency is increased in comparison with the efficiency of piezoelectric energy harvesting, and the energy of the low-frequency vibration can be captured by different reasonable designs.

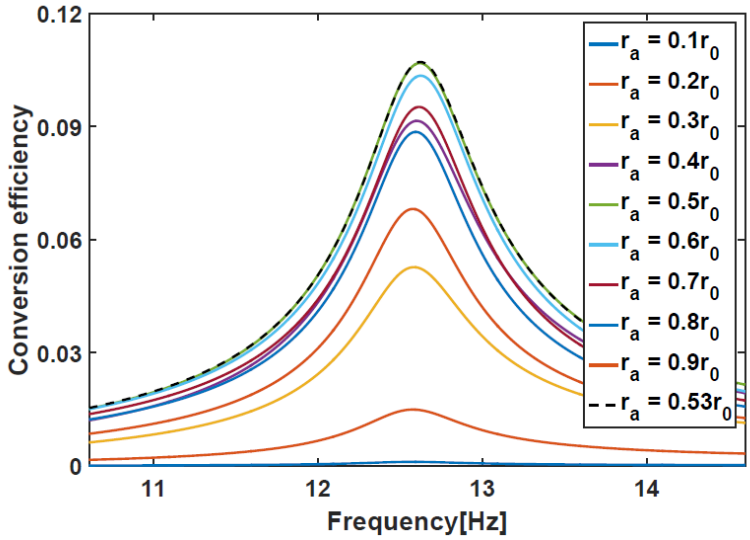

Fig. 2

Experience on calculating laminar flame speed in the framework of RANS equations with simplified chemical mechanism

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One way of the premixed combustion development is propagation of combustion wave due to upstream diffusion of heat. This mechanism is realized in wide range of practical tasks. Heat diffusion is usually intensified by turbulence, but on the level of smallest turbulent eddies the process is determined by molecular heat conductivity. Classical model analogue is one-dimensional laminar propagation of flame in combustible mixture. This report is devoted to various methods for estimation of the Laminar Flame Speed (LFS). LFS is widely used for estimation of characteristic time of combustion in models of Turbulence-Combustion Interaction (TCI).

A simple estimation of LFS was proposed by Zeldovich, Frank-Kamenetsky and Semenov. Brief description of this theory is given. Disadvantage of this theory is that it is based on series of strong simplifications (in particular, Schmidt number is taken to be equal to 1). This report is focused on attempts to calculate LFS based on full 1D Reynolds equations (RANS) for multicomponent gas with finite-rate reactions, closed by some simplified kinetic scheme.

It is shown that direct simulation of laminar flame based on RANS equations is complicate because of motion of acoustic waves along the duct. In further attempts, pressure is taken to be constant along the duct. Different ways to find the reference frame, where the combustion wave is steady, are considered. Influence of boundary conditions is shown. The method, based on transition to the stream function, is chosen as the best way to solve the problem.

Analysis of the effect of water injection in the supersonic jet of liquid-propellant rocket on gasdynamic loadings acting on launchers

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Keywords: injection, coolant, cross-flow, exhaust jet, launcher

The main object of this work is to estimate the effectiveness of reducing the gas-dynamic loadings on the launcher by the water injection into the exhaust jet of the liquid-propellant rocket engine.

A design model of the launcher was created to study this method conceptually corresponding to the available launch sites (Vostochny cosmodrome, Baikonur cosmodrome, test benches). Water used as a coolant was injected into the exhaust jet in various ways. The results were evaluated by the change in the distribution of static pressure and static temperature on the vertical, inclined and horizontal walls of the launcher. The studies were performed using the Spallart-Allmaras turbulence model for gas with variable heat capacity, viscosity and thermal conductivity. The Discrete Phase Model method was used to simulate a two-phase medium, the disintegration of the jet and drops was performed using the KH / RT model. [1]

The work was done in two stages: the first one is a test calculation performed with water injected in the liquid and gaseous phases into the cross-flow. At the second stage, the efficiency of reducing gas-dynamic loadings was evaluated. The calculations were performed on unstructured meshes constructed using the Cut Cell method. The average number of cells for test calculation is $N_1 = 10^5$, for calculation with models of launchers is $N_2 = 3 \cdot 10^6$. The AUSM + splitting scheme was used. [2] A comparison of the results of numerical calculation with an analytical solution was conducted, analytical solution obtained by the formulas verified in the works [3][4].

Two methods of coolant supply were compared, the most suitable method was chosen. Calculations were carried out with an imitation of the exhaust jet of the RD-218 engine with an oxidizer excess ratio $\alpha = 0,9$, and nitrogen, water vapor, and carbon dioxide were taken as combustion products. According to the results of all calculations it was made a conclusion that the injection of a coolant into the exhaust jet is an effective method of reducing the gas-dynamic loadings on the starting devices. An important role in cooling efficiency is played a jet depth penetration of liquid or wapor into the exhaust jet. The most affecting cooling is observed when water is supplied from four sides and at a flow rate equal to the mass flow rate of the combustion products through the nozzle. Using this method, it was possible to reduce the temperature of the lower wall by 35-55%, significantly reduce the temperature gradient on the walls, reduce the maximum local temperature values by 40-47% and decrease the pressure gradient on both walls.

References

1. J. C. Beale and R. D. Reitz. "Modeling Spray Atomization with the Kelvin-Helmholtz/Rayleigh-Taylor Hybrid Model". Atomization and Sprays. 9. 623–650.1999.

2. M. S. Liou. "A sequel to AUSM: AUSM+". Journal of Computational Physics. 129. 364–382. 1996.

3. S. Freitag and C. Hassa. ”Spray Characteristics of a kerosene jet in cross flow of air at elevated pressure” ILASS 2008, 12-1-7, Como Lake, Italy. ISBN 978-88-903712-0-2. 2008.

4. Yong Seok Hwang1 and Yu in Jin "The penetration characteristics of the normally injected kerosene liquid jet in high Weber number flow», 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Denver, Colorado, August 2009

Validation of models for calculating the combustion of hydrogen in a supersonic flow according to the results of the accurate physical experiment

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Keywords: supersonic combustion, validation, hydrogen combustion.

Today in the world there is an increased interest in the development of a hydrogen scramjet, which is considered as part of a combined propulsion system for hypersonic civil aircraft and the first stages of space systems for outputting payload to orbit. Such engines are developed in the framework of international projects HEXAFLY-INT, HIKARI, SKYLON [1-2] and a number of Chinese projects. In the presented projects fundamental research workflow in the combustion chamber are conducted

In the development of high-speed hydrogen combustion chambers, much attention is paid to improving the efficiency of the organization of the mixing of the fuel-air mixture and the fullest use of the energy stored in the fuel. The effectiveness of the mixing and combustion of hydrogen in a supersonic flow is influenced by many factors that can be attributed: channel length, mass-flow rate, equivalence ratio, number of struts, pressure drop on struts, the presence and height of ledges and channel niches. Conducting accurate physical experiments with a change in all of these factors in wide ranges is a very laborious task. For this, numerical methods are used. To obtain reliable results, it is necessary to validate the models used, based on the results of known experiments.

When the flow velocity increases, the characteristic time of chemical reactions becomes comparable with the residence time of the mixture in the combustion chamber. This feature of high-speed flows leads to the need to use the mechanisms of chemical kinetics in the numerical simulation of the combustion of hydrogen in air flow.

In this work, the influence of the used computational methods and boundary conditions on the solution of the problem of burning a hydrogen-air mixture in the mixing layer of an axisymmetric hydrogen jet with a co-current model high-enthalpy air and the comparison of the obtained data with experimental ones was carried out [3]. The calculated geometry of the problem repeats the configuration of the experimental setup. Menter and Transition SST turbulence models, Dimitrov [4] and Hanson-Hong [5] chemical kinetics mechanisms, the flamelet model, laminar finite-rate and eddy-dissipation concept were used, the turbulent viscosity at the input to the calculated area was varied. It is shown that the method of accounting for the pulsation component in determining the concentrations of components has a decisive influence on the quantitative and qualitative character of combustion in the mixing layer. The best agreement with the experimental data was obtained using the flamelet model. It is shown that the use of various mechanisms of chemical kinetics does not have a significant effect on the result, which means that the convective mixing mechanism is decisive in this task. The level of turbulence at the entrance to the computational domain also has a significant impact on the result. Figure 1 shows the distribution of water concentrations in the cross section of the computational region at a distance from the entrance (the ratio of the length to the diameter of the strut is 27.9). It can be seen that different levels of turbulent viscosity at the inlet lead to both quantitative differences in the concentrations and qualitative (displacement of the peak of concentrations to the left with increasing turbulent viscosity at the inlet).

The reported study was funded by RFBR according to the research project №18-31-00254.

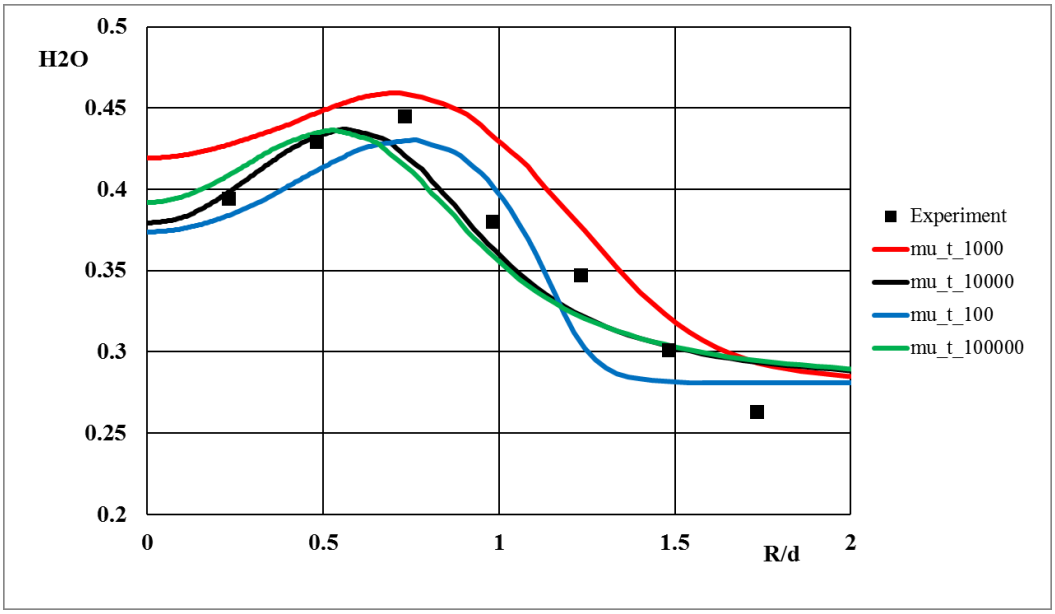

Figure 1 – The distribution of water mass fractions in the cross section for different values of turbulent viscosity at the entrance to the calculated area

References

J. Steelant, M. Marini, G. Pezella, B. Reimann, S.L. Chernyshev, A.A. Gubanov, V.A. Talyzin, N.V. Voevodenko, N.V. Kukshinov, A.N. Prokhorov, A.J. Neely, C. Kenell, D. Verstraete, D. Buttsworth. Numerical and Experimental Research on Aerodynamics of High-Speed Passenger Vehicle within the HEXAFLY-INT Project. Proceedings of 30th Congress of the International Council of the Aeronautical Sciences, ICAS2016-0353, 2016.

U. Mehta, M. Aftosmis, J. Bowles, S. Pandya. Skylon airframe aerodynamics and SABRE plumes. 20th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, 2015, AIAA 2015-3605.

Evans J.S., Schexnayder C.J., Beach H.L. Application of Two - Dimensional Parabolic // Computer Program to Prediction of Turbulent Reacting Flows. NASA TP-1169. 1978.

Dimitrow V.I. The maximum kinetic mechanism and rate constants in the H2 - O2 System. React. Kinetic Catal. Lett., Vol. 7, No. 1, pp 81-86, 1977.

Hong Z., Davidson D.F., Hanson R.K. An improved H2/O2 mechanism based on recent shock tube/laser absorption measurements. Combust. Flame, Vol. 158, pp 633-644, 2011.

Recent development in mechanics of soft materials and machines

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The elegance of nature's designs has inspired scientists to create soft machines. With development of soft machines, the mechanics of soft materials which are used by soft machines becomes an emerging field of applied mechanics. Therefore, the mechanical behaviors of soft materials are new and very current research topics, i.e. the large deformation studies of hydrogels, liquid crystal elastomers, dielectric elastomers and shape memory polymers (SMPs).

In this presentation, we will review some of the recent works aligned with the direction of providing a better understanding of soft materials (gels, SMPs etc.). Then the transient deformation process of polymeric gels and numerical implementation for large deformation kinetics of polymeric gels are studied using the finite element method (FEM). The neutral and environmentally sensitive (such as temperature, pH-value, magnetics and light) hydrogels are investigated. For the SMPs study, we developed different constitutive models which can be used for different SMP materials and can be used for large strain large deformation analyses. To validate the model, simulated and predicted results are compared with experimental results. Finally, as many issues related to the mechanics of hydrogel and SMPs deformation behaviors remain open, we will list some outlines for plausible future directions in the research of computational mechanics of soft materials/machines. Furthermore, we will overview the recent development of computational mechanics in the study of soft materials and machines over the worldwide, especially; the advances of computational mechanics for soft materials in different research groups will be discussed and reviewed.

Small Satellites

Aerospace infocommunications network EFIR satellite constellation

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JSC Russian space systems, Moscow, Russia

The EFIR space system is a satellite communications system with a global coverage providing voice communication and data transmission services.

The EFIR space system consisting of 640 small spacecraft will provide a full coverage of the Earth surface and become “a space data bus” to ensure data communications services. The space constellation in the orbit of 1100 km with the opportunity of data transmission through the intersatellite link will allow one to choose optimum traffic routes without using ground facilities.

The orbits of the main competitive systems: Oneweb and SpaceX, make more than 1100 km, and various frequency ranges used by the systems will make it possible to provide communications services to systems without the influence on each other.

Users of the EFIR system are people, sensors, transport vehicles including unmanned, space, and aviation vehicles. Communications services will be available in real time and on a global scale. By means of low-speed and high-speed user communication links, the following services will be provided:

- Personal mobile communication
- Communication channels for IoT (Internet of things) devices
- Channels to control unmanned vehicles and spacecraft
- Internet access from a personal mobile terminal
- Internet access in transport
- Data relay from unmanned vehicles and spacecraft

The additional payload is the Air transport monitoring (ADS-B).

A multilevel structure of the EFIR space system permits one to provide a wider range of services to various users: ground objects, unmanned vehicles (UV), and aircraft.

The advantages given above are possible thanks to the EFIR spacecraft weighing no more than 400 kg with the onboard power supply system of 1500 W.

Main design stages of the EFIR communications system are scale modeling, creation of technological spacecraft, development of instrument technologies, creation of spacecraft prototypes, serial production of spacecraft, and constellation deployment. The given services will be available since 2025. A full deployment of the system will begin in 2026.

The EFIR space system unites manufacturers, economic partners, and retailers to achieve general goals to provide the B2C, B2B, and B2G users with voice communication and data transmission services.

Microsatellites and educational programs

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The review is presented on educational projects in space physics with microsatellites.

The microsatellites history and their usage for educational purposes began in USSR [1]. In Russia this experience was developed by the microsatellite Kolibri-2000 launch (in 2002 by the cargo spacecraft Progress in the frame of the Russian Segment of International Space Station infrastructure) which was initiated by Australian and Russian schools [2]. The International Astronautical Federation gave Kolibri-2000 status 'the first scholar research satellite'.

Some microsatellites were launched for different jubilee dates of leading universities, for example MSU-Tatiana, Ubileynyi, Baumanets etc. A radiotelemetry standard for these satellites is based on the recievers/transmitters, working in the amateur band and developed in the laboratory of NILAKT DOSAAF (Kaluga).

Under the Presidium RAS Program for investigation of new physical processes in atmospheric terrestrial flashes the microsatellites Chibis-M was developed in IKI. There was not only design of satellite but its production and all cycle of necessary ground tests. Launched from Progress spacecraft Chibis-M worked on orbit in 2012–2014 and became first academic microsatellite in Russia [3, 4]. Command and telemetry were also made with usage of technical systems of IKI. With usage of the results of scientific publications and with usage of dynamic model of Chibis-M in IKI exhibition we developed lectures' course for students and pupils.

Long-Range Program of Scientific Research and Experiments (NPI) on ISS till 2024 contains section devoted to the space researches education and promotion. In particular, one of the bright example of such experiments, realizing these days for pupils specialized in physics and mathematics, is SPHERES developed by NASA. This experiment uses equipment imitating microsatellites.

We discuss results and questions of the academic microsatellites research with problems of NPI for the future IKI microsatellites Chibis-AI and Trabant.

References

1. Research of solar-terrestrial relationships on the micro-, nano-, and picosatellites: Materials of scientific session of solar-terrestrial relationships Space council RAS. Ed. A.A. Petrukovich. M.: IKI, 2015, 184 p.

2. Klimov, S.I., et al. Results of in-flight operation of scientific payload on micro-satellite “Kolibri-2000”, Acta Astronautica, Volume 56, Issues 1-2, January 2005, Pages 99-106, 2005.

3. Zelenyi L., Gurevich A., Klimov S. et al. Academical microsatellite Chibis-M. Cosmic Research, 2014, V.52. P. 87.

4. Dolgonosov M.S., et al. “Solitary” Trans-Ionospheric Pulse Pairs onboard of the microsatellite “Chibis-M”. Adv. Sp. Res. 2015. v. 56. № 6. p. 1177–1184.

Sun-Venus Lagrangian point satellite for the Venera-D mission

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Keywords: trajectory design, Lagrangian L1 point, Venera-D

A satellite in the vicinity of the Lagrangian point L1 of the Sun-Venus system has been proposed as an additional element of a future space mission to Venus, titled Venera-D. The placement of a satellite in the vicinity of the L1 point, which keeps a constant location on the Sun-Venus line at the distance of about one million km from Venus, enables unique scientific studies, such as the observation of atmospheric ion escape, permanent space weather near Venus or dayside global albedo monitoring [1].

The Venera-D mission is planned to be launched in 2026 and implies landing and orbital parts. The landing part includes a principal lander, with the expected life-time of 2 hours, and a smaller station, which will operate about 2 months on the Venus surface. Currently, the baseline mission includes one orbiter in a near-polar highly-elliptical orbit with pericentre altitude of 400 km and 24-hours orbital period [2]. The main goal of the orbiter is to ensure data-relay from the main lander during its parachute descent and life-time on the surface. For this purpose, the orbiter separates from the landing module at least 3 days before the arrival to Venus, and is inserted into a trajectory, counter to the lander's arrival to Venus hyperbola (see Fig.1).

Technical constraints on transfer of the proposed satellite into an L1 point orbit are mostly related to the main orbiter's trajectory and operational orbit. In this work we present feasible solution for such a transfer and characterise possible orbits in the vicinity of the Lagrangian point.

The main advantage of a scenario we propose is that the insertion into L1 point orbit of the small satellite is performed by making use of the main orbiter's propulsion. Hehce, only trajectory correction manoeuvres may be required to be

performed by the small satellite. Another advantage is a very low station-keeping cost (about 1 m/s per year) in an orbit in the vicinity of the Lagrangian point. These opportunities allow mission to include a satellite of mass about 50 kg, which can operate about 3 years in the orbit, namely about 9.7 orbits around L1 point, and enable new possibilities for Venus study.

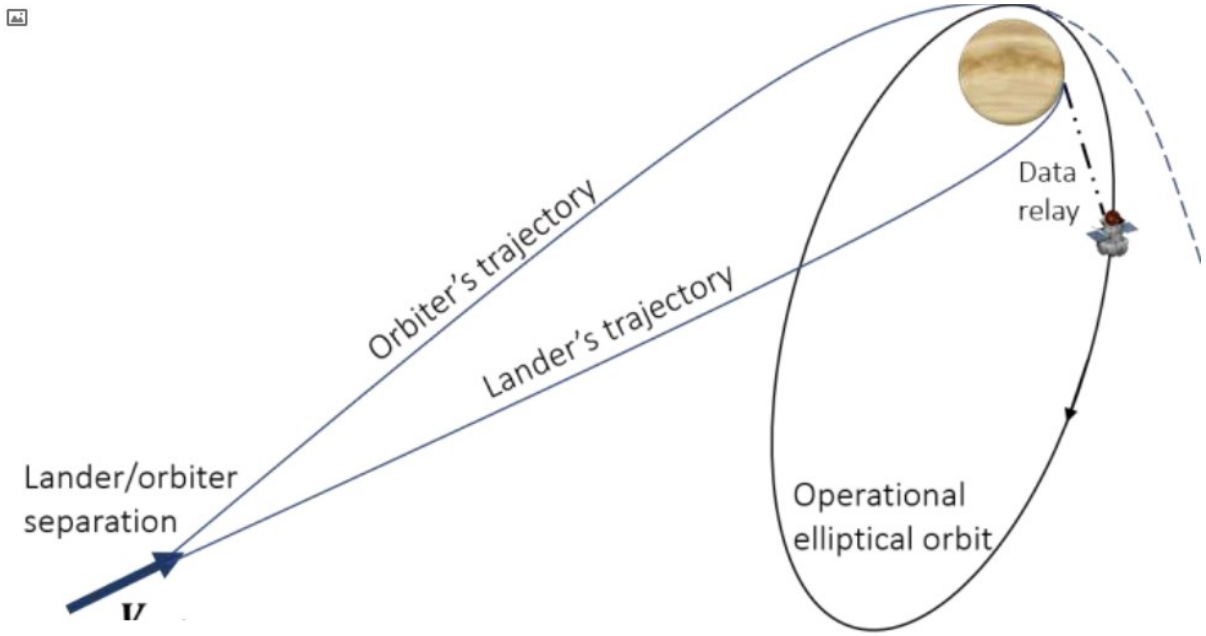

Fig. 1 Mission scenario

References

1. Zasova L.V., et al, At 9th Moscow Solar System Symposium, 2018, Russia.
2. Zasova, L., et al, Joint Science Definition Team Report, 31 January 2017.

School scientific experiment on board satellites "SiriusSat-1,2"

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SPUTNIX

SPUTNIX Company has developed a complete low-cost CubeSat kit OrbiCraft-Pro intended for university missions, the kit allows to create a satellite easier, faster, and cheaper due to standardization of its subsystems, use of COTS electronics and developed software libraries and collateral teaching material. This solution lets scientific teams focus on the payload and mission planning instead of developing a new satellite.

The kit represents a set of electronic and mechanical parts for manual assembly of CubeSat-compliant spacecraft. Extremely low-cost in comparison with known systems, at the same time, robust design allows combining these scenarios in one product by sacrificing guaranteed in-space lifetime of a spacecraft.

Onboard computer is represented with Raspberry-Pi Compute Module model CM3 that provides a great amount of ready-to-use solutions and code examples for any case.

Power supply unit provides a unique feature to connect either expensive GaAs solar panels or low-cost silicon ones during educational process or for missions with low power consumption.

OrbiCraft-Pro transceiver is compatible with OrbiCraft-Pro PC/104 pinout and has an additional feature of UART interface with Raspberry-Pi. That means that if there were any critical troubles with Rapsberry-Pi main operation system, which is generally Raspbian, it can be fixed from the ground via terminal connection with Raspberry low-level bootloader.

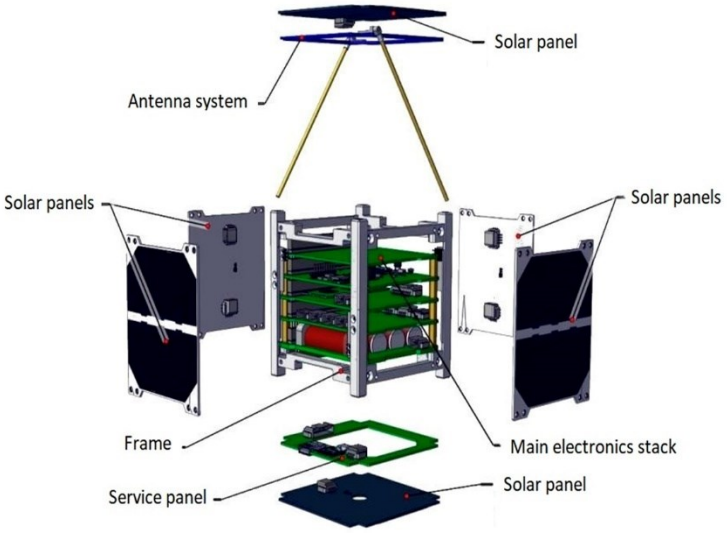
The main computer slot supports both Raspberry-Pi CM1 and CM3 modules, the last one is basic configuration, but CM1 can be used to reduce power consumption at the expense of compute facilities.

In the summer 2017 an OrbiCraft Pro 1U kit was provided to Educational Center Sirius in Sochi, Russia for development of the first Russian satellite created by group of talented children. As the result of the efforts became a space mission SiriusSat-1 and SiriusSat-2 [1] based on an engineering model of CubeSat 1U.

The mission was included to the Roscosmos program of free educational launches. The scientific and educational nanosatellites were delivered to the ISS in July 2018. On August 15th 2018 during the planned EVA on the ISS, cosmonauts have launched the satellites into outer space.

The payload of satellites consists of detector of charged particles and gamma radiation. The detectors were developed by MSU Skobeltsyn Institute of Nuclear Physics. The data acquired from the detectors is useful in circumterrestrial space studies and when monitoring radiological environment.

SPUTNIX can provide a solution for those teams who have problems to pick up the appropriate set of compatible components by themselves. The platform can be brought in on different steps of development – from starter space technologies study to satellite launch in time shortage conditions and on every of these steps all systems are compatible and can be easily and cheaply replaced with new one in case of damage.



Reference

1. Educational Center “Sirius”, “Fond talent i uspekh”, p.32-34, Sochi 2017

Microsatellite project for sounding upper atmosphere

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Keywords: heterodyne spectroscopy, infrared, remote sensing, greenhouse gases, CubeSat.

Accurate knowledge about properties of the upper atmosphere is highly demanded in many areas nowadays. Among them are: climate simulation, weather forecasting, small satellites lifetime prediction, low-orbit space objects motion control. Currently there are no reliable methods for obtaining necessary information about processes occurring in the upper atmosphere, in particular, about its dynamics. In order to make progress in these problems, we propose the development of a laser heterodyne spectroradiometer based on a microsatellite with CubeSat form factor.

The probe will measure the following parameters of upper atmosphere layers: atmospheric density, mixing ratio of CO_2, O_2, H_2O, CH_4, their vertical distribution, and wind speed component along the sounding track. The laser heterodyne NIR spectroradiometer developed by the MIPT's Laboratory for Applied Infrared Spectroscopy (AIRS) will be employed for data acquisition. The advantage of orbital measurements in comparison with ground-based ones is an opportunity to collect data along the flight trajectory that allows broadening the measurement coverage area global-scale mapping. The main advantage of the heterodyne spectroscopy application is extremely high spectral resolution of $\lambda/\delta\lambda \sim 108$ that allows to completely resolve profile of an individual rotational line in the vibrational-rotational spectrum of molecules of interest. Despite the narrow spectral range, all foregoing gases could be measured simultaneously by using several tunable diode lasers and selecting their tuning ranges. Applying compact NIR diode lasers and

single-mode optical fiber provides significant reduction of weight and dimensions of the spacecraft payload.

Cubesat form factor is supposed to be used for mission implementation. Microsatellite includes power supply, radio link, attitude control and payload modules. The dimensions of the instrument are limited by the reference gas cell and meet the 6U standard. Peak power consumption of the satellite does not exceed 50 W, and weight is no more than 10 kg. Attitude control system has an error less than 6 angular minutes for successful measurement conduction. The on-board data processing system is based on FPGA. The daily data volume, that is approximately 12 Mbit, is sent to Earth by the X-band transponder during single passby. The most optimal satellite operation mode is achieved at a polar Sun-synchronous orbits with the altitude about 600-1000 km and satellite lifetime more than a year.

KeRC activities in the field of small satellite EP

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KeRC

Keywords: small spacecraft, electric propulsion, Hall thruster, ion thruster, cathode, flow control unit

Small spacecraft are among the most thriving directions of recent space technology development. Potential of small spacecraft have not been completely realized to date, so requirements for their various subsystems, including propulsion equipment, are still have not been utterly figured out. In the absence of strict requirements, many of the activities are performed as initiative works.

The report describes results of KeRC developments in the field of low-power electric propulsion, which are Hall and ion thrusters, their cathodes and flow control units. Hall thrusters KM-32 and KM-45, created with use of commercial funding sources, provide 11 mN and 18 mN of thrust at 200 W and 330 W of power respectively. Its is also possible operating KM-32 in power range of 100 to 300 W and KM-45 in the range of 200 to 400 W. KM-45 thrusters have been used for orbit correction of Indian GSAT-9 satellite since 2017.

There are recent activities held for development of IT-500 ion thruster, which is capable for operating at 50 W to 150 W of power, providing 2 mN to 5 mN of thrust.

There was a cathode developed, with 300 mA current and record-winning low propellant consumption of 0.03 mg/s, for ion beam neutralization.

There is also a flow control unit developed for low-power electric thruster gas distribution, which is capable to provide and control propellant input to anode and two cathodes while having complete internal gas line redundancy. Its mass is 350 g.

The described efforts allow speaking of establishing a significant scientific and technical basis that may be used at development of small spacecraft electric propulsion systems.

Tabletsat microsatellite platform and its applications

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Keywords: microsatellite platform, distributed space system, multipurpose space system.

The contemporary trends in satellite development is turning to multipurpose spacecrafts, providing quick development of multi-satellite constellations of different purposes based on uniform satellite platforms. The considered herewith TabletSat microsatellite platform provides an opportunity for creation of multipurpose space system with affordable costs of development, assembling and maintenance.

TabletSat microsatellite platform is a set of onboard devices and structural elements, sufficient for small spacecrafts from 10 kg to 200 kg development, ensuring the integration and operation of third parties' payloads. Payload mass may be up to 100 kg, with daily average consumption up to 200 W. The Platform provides the transfer rates of payload data up to 100 Mbps (eventually up to 300 Mbps), with up to 128 GB storage capacity. Pointing accuracy is up to 15 angular seconds; position accuracy is up to 20 m. Data bus interfaces are CAN2B and SpaceWire, moreover additional interfaces such as RS-422/485, SPI etc are implemented. Power bus is 12V±10%. CoTS hardware components provide lifetime of 3...5 years on 400…800 km height orbits.

TabletSat platform main idea is unification of mechanical, data and power interfaces. In conjunction with COTS components, it gives the reduction of time and costs on development, assembly and testing of spacecraft. The majority of onboard devices and subsystems of the TabletSat platform is created by the SPUTNIX Company in cooperation with MIPT.

Control and measurement instruments for calibration and functional testing of devices and subsystems, and test benches for semi-natural modeling of microsatellite platform operation were developed.

There is also the ground control station created for communication with spacecraft at frequency band 435…438 MHz. Basic ground control station is located at Skolkovo; also distributed network of several similar ground stations is scattered throughout the Russian Federation territory.

In consequence of accomplished results, the time of integration of the new payload from the start of the work up to ready-to-launch may be reduced to 8 months (depending on required works' degree of complexity). Herewith the time of production, testing and assembling (without development) may be reduced to 3 months. For example, the technology demonstrator satellite TabletSat-Aurora, which ensured the piloting skill to the platform's instruments, was created in 8 months. The current technological readiness level of the platform is 4-5.

TabletSat platform provides integrating different payloads and executing of different missions, for example:

- Earth remote sensing in visible spectral band, with resolution 1m and more;
- Earth remote sensing in IR band, with resolution 50m and more, with thermal resolution up to 1K;
- Radar remote sensing with resolution 3m and more;
- Scientific mission;
- Automatic identification of the vessels;
- Communication;
- Experimental mission.

During platform development, the solutions allowing the distributed calculations between devices of the single spacecraft were comprised, and after integration of the inter-satellite communication line, the calculations may be distributed between several spacecraft. Therefore, the integration of the inter-satellite communication line and thrusters for orbit correction, the available background will allow in the short time to develop and create the multipurpose space systems in form of self-organized and full-connected satellite constellation.

As the result, the developed platform allows creating both individual miniature spacecraft for different tasks, and multipurpose distributed satellite systems for more ambitious tasks. The challenge of TRL increasing up to at least 6-7 may be accomplished by launching of 1-2 technology demonstration satellites.

Writing with Sunlight: a Feasibility Study of a CubeSat Formation Mission

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Keywords: CubeSat, formation flying, space mirror, satellite flares

Small satellites formation flying missions are used for various purposes where a large number of satellites serve as distributed instruments for atmospheric sampling, construct a distributed antenna platform, make a distributed aperture for imaging, etc. We study a number of spacecraft equipped with solar reflectors. These satellites fly within a formation. In some lighting conditions such formations can be visible from the ground and provide graphic images in the sky as illustrated by Fig. 1. This effect is known mainly due to Iridium satellite flares, and can be used to test the formation quality.

Firstly, the definition of observability is provided, which accounts for solar sails' reflective properties and geometry for any given orbit altitude. The parameters of the formation are estimated depending on the required image quality.

The core of the study focuses on the coupled orbital and attitude dynamics of the satellites. The solar reflector significantly influences the atmospheric drag and the solar radiation pressure acting upon individual satellites. It is essential to analyze these factors and study ways to employ them in the formation control along with other means, such as thrusters.

Numerical experiments have been conducted to study how the use of the differential drag technique [1] and the solar sail propulsion [2] can help minimize propellant consumption. A procedure has been developed that allows specifying the formation flying mission profile given the graphical image that should be reflected to Earth.

Fig. 1 An artist's impression of a tentative formation view from Earth

References

1. C.L. Leonard, Formation keeping of Spacecraft Via Differential Drag, M.Sc. Thesis, Massachusetts Institute of Technology, Cambridge, MA, July 1986.

2. Reichhardt, T.: Setting sail for history, Nature, 433 (2005), pp.678–679.

Evaluation of the quality characteristics of satellite systems by mathematical modeling

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Keywords: Simulation, satellite, orbital constellation, quality characteristics, communication, navigation, remote sensing of the earth from space

One of the urgent tasks is to promptly assess the qualitative characteristics of satellite systems for various purposes, the orbital grouping of which includes satellites in non-geostationary orbits. The difficulty in obtaining such estimates lies in the fact that the satellites of the orbital group continuously change their position, while they can be heterogeneous (have different technical characteristics), and the earth segment may be required for the operation of the system. The interest is not only the instantaneous "portrait" of the system at some point in time, but above all the integral estimates at a certain time interval corresponding to a specific value of reliability. It is not possible to obtain such an assessment by analytical methods. In most cases it is necessary to use mathematical modeling.

The article deals with the structure of a complex mathematical model aimed at solving the problems of analyzing the qualitative characteristics of satellite systems for various purposes. The requirements for software and mathematical support are substantiated. The materials on the analysis of qualitative characteristics of satellite systems on the example of existing and future communication systems, navigation systems and systems of remote sensing of the earth from Space are presented. The concept of "reference structure" is introduced and examples of its use in the analysis of satellite systems are given. The results of the analysis of perspective multi-echelon hybrid satellite systems focused on complex provision of communication, navigation and remote sensing services are presented.

Microsatellites as a part of the International Space Station's Russian segment infrastructure

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Space Research Institute of the Russian Academy of Sciences (IKI) and Energia Corporation has been developed and implemented a joint operation that has resulted in the construction of an experimental space platform for microsatellite orbit insertion in the framework of the Russian segment of the International Space Station (RS ISS) infrastructure.

Delivery of the educational microsatellite "Kolibri-2000" (mass 20,5 kg) developed and manufactured at IKI, which has been accomplished by means of ISS infrastructure in 2002, has been the first step of the fundamental research activity employing microsatellites. In spite of the small size, the satellite carried 3.6 kg of science payload, that facilitated a broad range of studies covering both "classic" space physics and space weather, atmospheric and ionospheric processes, presumably related to the thunderstorm activity. Those processes have been revealed by detection of electrons near equator. Activities related to space education have also been carried out.

In the framework of the project implementation various problems have been resolved for the first time, among them: multipurpose transportation and orbit insertion device capable of launching microsatellites with mass of 40-50 kg; in-flight testing of the orbit lifting scheme by means of Progress cargo space vehicle after completion of its main program, which yields a considerable economic effect; development of the fully functional microsatellite platform; implementation of test cycle and flight control schemes which may be employed in future projects; construction of the ground-based infrastructure of data acquisition based on the regular internet data flow and capable of serving for other similar projects.

Based in this platform, two microsatellites have been developed: educational spacecraft “Kolibri-2000” and “Chibis-M” [1] aimed at high-altitude thunderstorm discharges studies in the broad spectrum of electromagnetic radiation. “Chibis-M” has successfully accomplished its ballistic flight term (2 years and 8 months), which exceeds its guaranteed work term by 2.5 times.

In spite of limited mass and size of the spacecraft, its scientific program implied requirements on the information system which may compete with those of large-scale space projects on its functional parameters. However, due to innovative approach and latest achievements in information technology, this problem has been completely resolved under strict financial limitations. Chosen approach has been proven by flight experience.

Currently IKI is implementing R&D activity in the framework of the RS ISS science program, including:

- Instrumentation for thunderstorm studies (phase B);
- TRABANT instrumentation (phase A).

References

1. Zelenyi, L.M., A.V. Gurevich, S.I. Klimov, et al. Academic microsatellite “Chibis-M”. Cosmic Research, 2014, Vol. 52, No. 2, pp. 87–98

Mid-IR fiber components for space-borne spectroscopic instruments

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Keywords: fibers, mid-infrared, couplers

The active development of the silica optical fibers in the 80s of the last century contributed to the achievement of the theoretically minimal level of losses in fibers. For the mid-infrared the starting point for developing optical fibers was the achievement of the materials transparent in this range of the spectrum. Optical fiber devices in the mid-IR can be used for remote IR spectroscopy, in particular, to determine the components of various substances, environmental monitoring, for research in the field of photonics, laser technology, medicine and other areas [1]. There are three types of glasses with the necessary property of transparency: glasses based on heavy metal fluorides, polycrystals based on silver halides, and chalcogenide glasses [2].

For fiber coupler development the FBT (fused biconical taper) method was chosen. The fabrication technology is based on fusion of two single-mode fibers with a simultaneous extension of the heating zone with the purpose of receiving the smoothly varying biconical transition necessary for optical interconnection between fibers. We used single-mode optical fibers made of As2S3 glass with a core diameter of 6.3 μm and a cladding of 123 μm, a numerical aperture 0.17, and optical losses of ~ 400 dB / km at wavelengths 2.1-2.2 μm made in ICHPS RAS. Pre-preparation of fibers included embedding (FC/APC connectors) and polishing fibers.

The twisting of the fibers that is necessary to keep them in contact increases the bending of the fibers during heating and fusing. FBT method supposes to maintain

taper slope adiabatically to avoid core mode losses due to excitation of cladding modes. This means that radius change should be smaller than mode wavenumber difference

$$da / dz \le a\left(\beta_f - \beta_{cladding}\right) / 2\pi \,.$$

If this equation satisfied, the main loss path for the light in the fundamental mode is due to bending. The bending radius is defined as

$$R = \left(D^2 + z_0^2 / 2\pi\right) / D \,,$$

where D - is distance between fiber cores,

z_0 - is the helix period.

The losses estimation is defined as [3]

$$\alpha\left(\mathrm{R_{eff}}\right) = \frac{\sqrt{\pi}\kappa^2 \exp\left[-\frac{2\gamma^3 \mathrm{R_{eff}}}{3\beta_z{}^2}\right]}{4\sqrt{\mathrm{R_{eff}}}\gamma^{3/2}V^2 BesselK\left[-1,\gamma a\right] BesselK\left[1,\gamma a\right]},$$

here $\mathrm{R_{eff}}$ - is effective bending radius,

a - is core radius,

$V = \frac{\omega}{c} a\sqrt{n_{core}^2 - n_{clad}^2}$ - V number,

β_z - is the wavevector projection along the fiber symmetry axis, $\kappa = \sqrt{k_{core}^2 - \beta_z^2}$,

$\gamma = \sqrt{\beta_z^2 - k_{clad}^2}$. The resulting value of losses can be seen on the Fig. 1.

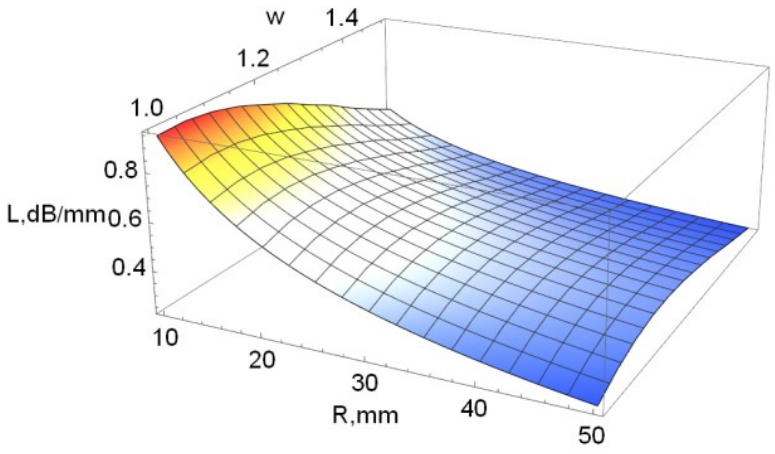

Fig. 1 Bending losses of chalcogenide fibers

References

1. Zhukova L.V, [et al.] Optical fibers for the mid-infrared range. Ekaterinburg: UMC UPI Publ, 2016. 247 p.

2. Snopatin G., [et al.] Churbanov M. High-purity chalcogenide glasses for fiber optics, Inorganic Materials, 2009. V. 45, P. 1439.

3. Schermer R.T., Cole J.H. Improved bend loss formula verified for optical fiber by simulation and experiment // IEEE Journal of Quantum Electronics. 2007, V. 43, P. 899-909.

The new type of antenna design for spacecraft

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Keywords: Patch antenna, strip antenna, multilayer horn antenna, LTCC ceramics, active phased array, AFAR.

Currently, there is a rapid development of space systems, which entails a significant increase in the number of spacecraft (SC) and an increase in the amount of transmitted information via communication channels. At the same time, the frequency resource in the allowed ranges L, S, C, X is significantly limited and in most cases are occupied by existing systems. In this regard, the developers of promising space communication systems are faced with the task of mastering the millimeter K, Ka ranges, for solving communication problems both between spacecraft and between spacecraft and ground stations.

When building communication channels in the K, Ka bands, the following problems arise:

– reducing the distance between the elements of antenna arrays;

– increasing requirements for precision manufacturing;

– increase in losses in transmission lines.

To compensate for the effects of these negative factors, it is necessary to use high-density mounting technologies. LTCC (Low Temperature Cofired Ceramics) technology has high electrical characteristics in the frequency bands up to 110 GHz and almost any number of layers, which is considered a good condition for high density mounting. The thermal conductivity of LTCC is 10 times higher than that of conventional printed circuit boards, which is also an advantage if it is necessary to remove heat from the semiconductor components.

Integration of the antenna into the input stage of the microwave module is a sequential step, which is necessary to prevent phase and amplitude errors due to the cable and connector. Due to the three-dimensional integration in LTCC, new types of antenna designs become possible.

References

Петер Улиг. Интеграция антенн в многослойные керамические подложки. Технологии в электронной промышленности, № 4 2010 г.

Панченко Б.А. Микрополосковые антенны / Б.А. Панченко, Е.И. Нефедов. — М.: Радио и связь, 1986. – 144 с.

Панченко Б.А. Электродинамический расчет характеристик полосковых антенн / Б.А. Панченко, Е.И. Нефедов и др. — М.: Радио и связь, 2002. — 256 с.

Сазонов Д.М. Антенны и устройства СВЧ: учебник для радиотехнических специальностей вузов. – М.: Высш. школа, 1988. 432 с.: ил.

Yu, A., Yang F., Elsherbeni A., A dual band circularly polarized ring antenna based on composite right and left handed metamaterials, Progress In Electromagnetics Research — Massachusetts: — USA: EMW Publishing Cambridge — Vol. 78, 2008 — P. 73–81.

Satellite dynamics with aerodynamic attitude control system

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Keywords: Satellite, Attitude motion, Gravitational torque, Aerodynamic torque, Active damping torque, Equilibrium orientation, Asymptotic stability

The problem to be analyzed in the present report is related to the motion of the satellite acted upon by the gravity gradient, aerodynamic and active damping torques. We assume that the center of pressure of aerodynamic forces is located on one of the principal central axes of inertia of the satellite and the active damping torque depends on the projections of the angular velocity of the satellite. This active damping torque may be provided by using the angular velocity sensors.

The action of damping torque both leads to new equilibrium orientations and can provide the asymptotic stability of the well-known equilibria of the satellite with aerodynamic attitude control system. A symbolic-numeric method, for determining all equilibrium orientations of a satellite in the orbital coordinate system for specified values of the aerodynamic torque and principal central moments of inertia in the case when the active damping torque is proportional to the projections of the angular velocity of the satellite is proposed. The conditions for existence of these equilibria of the satellite on the circular orbit were obtained.

The investigation of satellite equilibria was performed by using the Computer Algebra methods. The regions with an equal number of equilibria were specified by the construction of discriminant hypersurfaces. We have made a detailed analysis of the evolution of domains of existence of equilibrium orientations in the plane of system parameters. For the special equilibrium orientation, when two axes of the satellite-centered coordinate system coincide with two axes of the orbital coordinate system, the necessary and sufficient conditions for asymptotic stability were obtained. The transition decay processes of the spatial oscillations of the satellite for

various system parameters have also been studied. It was shown that the satellite oscillation frequency increased in angles pitch and yaw when the magnitude of aerodynamic moment increased. The value of the pitch angle approaches zero when the aerodynamic moment significantly increases.

We also study in this work the conditions of the asymptotic stability of the specific equilibrium orientation, when the principal central axes of inertia of the satellite coincide with the axes of the orbital coordinate system. This case exist when the active damping torque depends as a linear function on the projections of the angular velocity of the satellite. There is a wide range of damping and aerodynamic parameters, from which, by choosing the necessary values, one can provide the asymptotic stability of the satellite equilibrium orientation. The obtained results can be used to design passive aerodynamic attitude control systems for the artificial Earth satellites.

Active vibration analysis/control of inflatable space antenna reflectors

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Inflatable Structures are gaining immense importance in space science. The idea of large, ultra-lightweight and compactable membrane space structures has been proposed for various future interplanetary space missions. The performance efficiency of these reflective surfaces depends not only on the geometric accuracy of these surfaces but also on their vibration characteristics. It means the surface of the space structures (antenna reflector, telescope mirror, solar sail etc.) must be error free. So, to get high accuracy surface requirements of the space structures, the measurement and analysis of reflector's accuracy are necessary. Also, due to the periodic nature of symmetric reflectors, they will be very sensitive to even small irregularities due to manufacturing and material tolerances. Such irregularities can affect the vibration behavior significantly, by localizing the vibration modes and confining the energy to a region close to the source. The vibration challenges while launching by launch vehicle's high frequency and small vibration due to the electronics component of the satellite on orbit.

This paper considers a control system for vibration control of space membrane structures with piezoelectric actuators. Optimization and control techniques are discussed. Fuzzy Logic Control system is considered. Macro Fiber Composites (MFCs) are being used as PZT stack actuators. A robust comparison is shown between the PID controller and Fuzzy controller. A non-contact monitoring and control system has been proposed which has scope in future on complete development.

Small Satellites Structural Elements Tension Control by Quantum Sensor made of Modified Diamond with NV-center

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Keywords: small satellite, tension control, quantum sensor, modified diamond with NV-center, sensing element with frequency output

Purpose of the work is to get closer to practical implementation of quantum technologies in sensors made of modified diamond with NV-center for tension control of small satellites structural elements.

Structural elements of small satellites needs to be tested before and during use in space. In this case, the intensively developed quantum technologies in sensors have a bright prospect. Their main advantage is small size and theoretical ability to transmit data over long distance without wires. The main problem is that researchers study quantum processes that occurring in materials, but they do not show how this technology may be used in practical applications. Main result of the work shows that it is necessary analytically divide modified diamond with NV-center that is used as sensing device into two parts: 1) a sensing element made of specially formed vibrating diamond plate, 2) quantum NV-center specially created in this plate. This approach to sensor design allows implement known theory of vibrating converters for quantum sensors made of modified diamond with NV-center for their use in applications concerned with tension control of small satellites structural elements.

Research methods are based on hypothetical-deductive method and systematic approach to sensor design for tension control of small satellites structural elements.

Novelty and relevance of results consist in new, previously unpublished knowledge about a need to analytically divide primary converter made of modified diamond crystal into two parts to get possibility to measure a force or control a tension of small satellites structural elements.

Practical significance lays in getting possibility to assess the accuracy of the mechanical positioning of lenses and antennas or tension force of ropes in space tether systems.

Application possibilities consist in using future quantum sensors during calibrating radar and optical systems and study of tether systems.

Information-Measuring System for Endurance Test of Small Satellites Structural Elements

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Keywords: structural element of a small satellite, stress concentrator, stress-strain field, small size strain gauge, samarium monosulfide, information-measuring system

Purpose of the work is to design small size strain gauge for information-measuring system in order to provide endurance test of structural elements of small satellites

Small satellites structural elements often have small radii of curvature and it is important to provide their high stability to mechanical loads. **Relevance** of the work is concerned with the fact that mathematical apparatus of deformed bodies' mechanics has limited accuracy of mathematical description of complicated loading processes in frequency ranges of a small satellite operation. In addition, experimental study of stress-strain fields of small satellites structural elements cannot use traditional strain gauges because they are too large. To solve the problem, it is proposed to use samarium monosulfide strain gauges (semiconductor resistors), which have a high ohmic resistance and a small base. **In practice**, this lets to mount them on previously inaccessible places and minimize the influence of connecting wires on the results of measurements. The strain gauges also have a linear characteristic; they are resistant to radiation and applicable in a wide temperature range. The novelty of results is that for the first time the experimentally confirmed descriptions of main output characteristics of the strain gauges made of samarium monosulfide were obtained. This allow to increase accuracy of stress-strain state measurements in stress concentration zones of small satellite structural elements. The methods of analytical mechanics, experiment planning and probability theory and mathematical statistics were used during the work. Main **practical significance**

of the results lies in the fact that new opportunities for experimental study of stress-strain fields of small sized structural elements of satellites are now open in endurance tests. **Application possibilities** of the developed strain gauges made of samarium monosulfide as parts of information-measuring system allow solving complicated experimental tasks associated with investigation of structural elements endurance by studying tensions in condition of large gradients in strain and stress measurements.

High throughput X-band transmitters for the small satellites

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Keywords: satellite transmitter, coding schemes, modulation, cubesat

Modern satellites produce vast amounts of information. Thus, satellite performance is directly depending on the communication downlink throughput. The SAIT company develops X-band transmitters for 10 years and has made three steps to achieve near X-band bound for satellite transmitter.

At the first step, the SAIT has made a transmitter for the small satellites with wide range of parameters. It can transmit information with symbol rates from 0.1 Mbaud to 200 Mbaud with QPSK, 8PSK or 16APSK modulation. However, the transmitter has one fixed modulation, coding scheme and symbol rate per project. For another project, we need to change FPGA design slightly and to tune analog filters for different symbol rate or modulation scheme. This approach allows to reduce developing time and transmitter cost. These transmitters successfully operate at the ISS for 8 years and at four small satellites. We have adapted this design for the transmitter for the Moon spacecraft (Luna-25-27).

At the second step, we have implemented DVB-S2 adaptive stream. Thus, we can change the code rate and modulation scheme different according to the communication channel state (distance between the satellite and ground station, weather conditions, ground station with antenna size, etc). It is possible to switch the symbol rate in flight as well. This approach allows us to achieve maximum performance of the communication channel. DVB-S2 protocol makes possible to use commercial satcom demodulator at the ground station. This design will be tested at the new generation ISS downlink system next year.

At the third step, SAIT develops the cubeSAT transmitter. This transmitter can also be used for small satellites. We have increased symbol data rates up to 260 MSymb/s. Weight has been reduced to 380 gr, power consumption is 16 W.

Thus, we've got the spacelink with throughput up to 1,04 Gbit/s. Using two carrier with polarization diversity increases throughput up to 2,08 Gbit/s.

Space Debris

Determination of spacecraft non-orbital parameters

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Keywords: space debris, spacecraft photometry, multicolor photometry

In recent years, the problem of space debris has become particularly relevant. With the increasing number of launches, the number of both active spacecraft and related fragments, such as spent rocket stages, screen-vacuum insulation and other debris, is growing. What is important is not only the task of determining the orbits of similar objects, but also the task of classifying them. In addition to space debris, the task of determining the non-orbital parameters of the spacecraft during emergency situations for an additional analysis of the incident becomes relevant. For example, it is important to answer the questions: have the solar panels opened up? Have the antennas turned around? What is the orientation of the spacecraft?

Since the angular size of spacecraft visible from the ground stations often does not exceed the diffraction limit of the optics used, it is necessary to rely only on the parameters available for observation. The main parameter available for observation is the stellar magnitude of the spacecraft.

The main problem in determining the exact value of the magnitude is the atmosphere. Errors in the determination of the extinction coefficients and air masses, supplemented by scintillation noise and turbulence limit the accuracy of the measurements. However, in addition to multicolor photometry, that is, by determining the stellar magnitudes of spacecraft in various spectral ranges, it is possible to determine additional parameters, for example, color-indexes. With

systematic observations, it is possible to accumulate enough data to dynamically determine the orientation of the spacecraft.

This paper also discusses the application of differential astrophotometry methods to photometry of spacecrafts. Since most astrometric methods of differential photometry are based on the use of standard stars from well-known catalogs, photometry is also relevant without the use of generally accepted standards. The need for this arises due to not conveniently located stars on the celestial sphere. This is especially true of UBVRI photometry, where the most common catalog of standard stars, the Landolt catalog, consists of stars located within +/- 5 degrees from the celestial equator. It is obvious that for photometric measurements of spacecraft, this circumstance severely limits the use of such standards, since often the observed part of the orbit of the vehicles passes far from the celestial equator.

This paper is devoted to the analysis of existing techniques of astrophotometry as applied to photometry of spacecraft, and as a result, their definition outside the orbital parameters.

Geopolitical aspects of active debris removal: legal challenges and economic perspectives

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Keywords: active orbital debris removal, space security and sustainability, space law, space policy, space economy, space diplomacy

Exploring outer space occurs against the backdrop of not only brand new opportunities but numerous new challenges, threats and hazards to international security and global stability. In international relations, the role of the factor of force does not diminish including outer space. The desire to build up and modernize offensive weapons, the creation and deployment of its new types weakens the global space security system, as well as the system of treaties and agreements in the field of arms control. This competition is now being triangulated into outer space domain in a dramatic fashion raising new issues like weaponization of space, global competition for space resources, safety and security of space traffic in a much contested and congested environment, natural hazards like asteroids and orbital debris, not to mention such new challenges in the space domain like international terrorism, space cybercrimes, space piracy and sabotage of foreign space assets. The bloc approach to solving international problems does not contribute to counteracting the whole range of contemporary challenges and threats in space. The 'Founding Fathers' of the Outer Space Treaty did not and could not anticipate and predict all the revolutionary developments that were to come. Nor did they envision the extent of private business in space, growing satellite conglomerates at the GEO, CubeSats and so on, much less newly-emerging activities such as on-orbit servicing, active space debris removal, manufacturing in space, inhabited space stations, or the use of space mineral resources. The Lotus principle, also called the "permissive principle," instantly pups into some lawyers' head as soon as an active debris removal issue is touched upon. Stated in brief, the Lotus principle is "that which is not explicitly

prohibited is therefore permitted." For instance, does international space law permit the salvage and removal of non-functioning satellites? This article discusses several urgent issues related to international security and global stability in space with a prospective view to setting out a holistic and comprehensive approach to and developing a robust normative regime for promoting space security and safety of space operations, including active debris removal. In this context, issues such as the threat posed by orbital debris, the priorities of national security and space programs, the growing importance of commercial space industry actors and their economic perspectives are deemed crucial factors of overall space security and long-term sustainability.

Track detection using convolutional neural network

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Intensive exploration of outer space has led to the fact that more than 20,000 tracked objects with dimensions of more than 10 cm are currently in Earth orbit. About 1000 of them are active; the remaining 94% are space debris. This problem is a growing threat to space activities in an orbit. A method for predicting and preventing dangerous events is to determine the orbits of such objects. For these purposes, in particular, ground-based telescopes equipped with electronic photodetectors operating in the visible spectrum are used.

The primary step in determining the ballistic characteristics of the observed near-Earth object is its detection on frames obtained from observations. The optical signal reflected from space debris' fragments leaves a trace on the sensor. Eventually, energy of the signal is distributed among many pixels. As a result, it gets necessary to register low-contrast objects at small values of the signal-to-noise ratio.

Existing methods are divided into hardware and software means. The hardware methods include following: tracking the object, i.e., turning the telescope in sync with the visible movement of the object and time-delay integration when the charge transfer rate in the CCD matrix corresponds to the speed of the visible movement of the object. However, these methods require a priori knowledge of the object's orbit. Software methods include computer vision techniques, such as applying various filters, Hough transform, threshold processing, statistical methods, etc. Nevertheless, at present there is no universal algorithm for solving this problem.

However, there is another solution - the use of convolutional neural network. Modern convolutional neural networks in the problems of detecting objects in images show results close to the capabilities of the human eye and even superior to it. This paper discusses the use of convolutional neural networks in detecting a track left by a near-earth comic object on frames obtained from the observations with a ground-based telescope. The process of training the network, as well as obtaining a large training sample, consisting of several thousand frames with labeled objects, is considered. The results are presented.

Project of space-rocket system intended for disposal of space debris at geostationary orbit

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Keywords: space-rocket system, rocket “Soyuz 2.1b”, platform “Express-2000”, space debris

Introduction

We study problem of appliance of exist spacecraft with electro engines for transferring fragments of space debris (FSD) from geostationary orbit (GSO) to disposal orbit. For that we use combined system, which include rocket, booster with impulse chemical engine and spacecraft debris collector (SDC) with electro rocket engine of low-thrust. As rocket we consider “Soyuz 2.1b” missile, as booster we consider upper-stage rocket “Fregat”, as prototype of SDC we consider space platform “Express-2000”.

We consider next ballistic scheme:

1. Rocket “Soyuz 2.1b” inject booster and SDC to reference orbit;
2. Booster transfer SDC to geostationary transfer orbit via impulse engines;
3. SDC, using its engines of low-thrust, move to area of first FSD at GSO;
4. SDC carry out series of operations with FSD – closing with it, fixed on-board, transferring to disposal orbit and return to GSO to next fragment of FSD.

We solve this problem in two stages. At first stage we optimize combined transfer to GSO. At second stage we analyze possibility of disposing of FSD at GSO – calculation of number of disposed FSD and total duration of operation.

Due to impulse chemical engine booster “Fregat” transfer SDC (i.e. platform “Express-2000”) to geostationary transfer orbit with parameters – semi major axis 16500 km, eccentricity 0,6.

Next SDC move to GSO along optimal trajectory with next characteristics: gains of characteristic velocity 4,6 km/s, mass of working fluid 850 kg. To improve (decrease) duration of this transfer, we propose to modernize space platform "Express-2000" (i.e. SDC). We include number of engines to 12, therefore it thrust is equal to 0,966 N, and duration of transfer is 157 days.

Some results are plot at figures. At fig. 1 we plot time history of orbit perigee Rπ, apogee Rα and inclination i, at fig. 2 – time history of control program (thrust angle in perigee Ψπ and apogee Ψα). As time we consider gains of characteristic velocity.

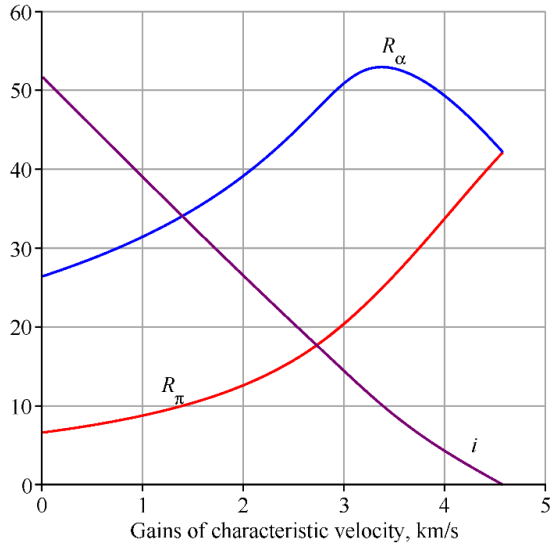

Fig. 1 Time history of orbit perigee Rπ, apogee Rα and inclination i

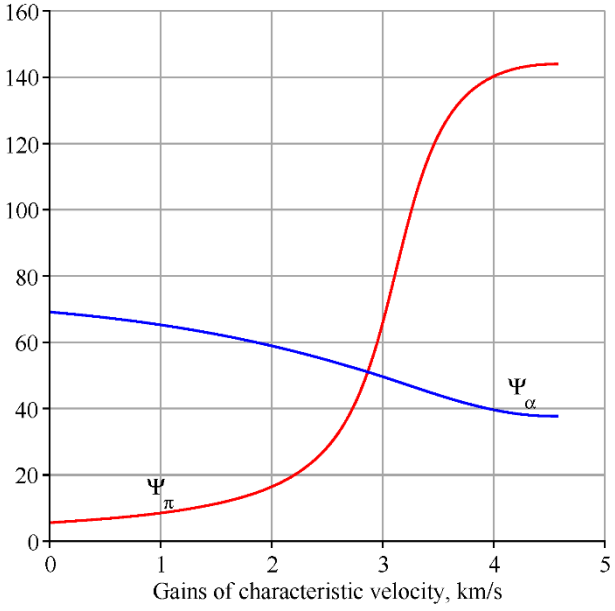

Fig. 2 Time history of control program – thrust angle in perigee Ψπ and apogee Ψα

After transferring SDC to GSO, it carries out series operations of FSD disposal. One operation contains two stages. At first stage SDC closing with FSD, fixed it on-board and transfer it to disposal orbit. At second stage SDC return to GSO to next fragment of FSD. Trajectory of FSD motion at one circle is plot at fig. 3.

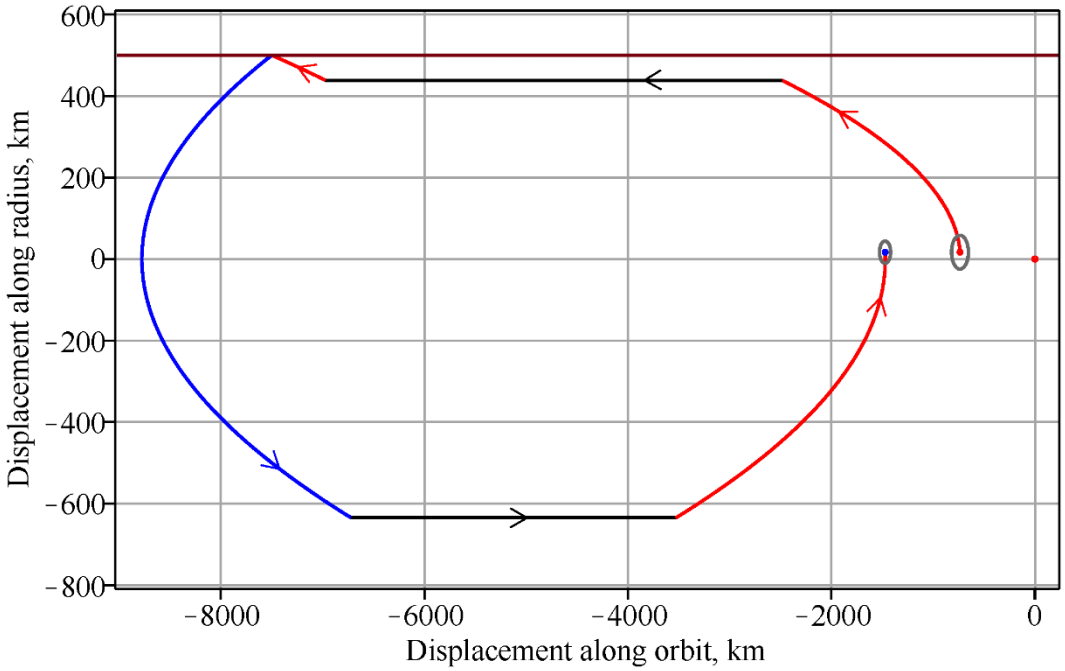

Fig. 3 Trajectory of FSD motion at one circle

SDC can carry out this maneuver by 4,47 days, it require 16,9 kg of working fluid. Summarizing, we can dispose 18 FSD from GSO during 0,65 years. Our research obtain that we can design the space-rocket system for disposal of space debris at geostationary orbit, which include rocket “Soyuz 2.1b”, booster “Fregat” and spacecraft debris collector that prototype is space platform “Express-2000” with increased number of engines.

Analysis of the ISON network contribution to the solution of near-Earth space monitoring tasks

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Keywords: space debris, optical telescope, measurements, orbit, accuracy, catalogue, conjunction analysis

Number of dead satellites, various stages of missiles and fragments accompanying launches and resulting from orbital destruction, has reached the level when it begins to pose a serious threat to the functioning spacecraft, the ecology of the Earth and the near-Earth space. Therefore, further exploration of the near-Earth space is impossible without knowledge of the current situation, analysis of sources and regularities of evolution of space debris population. Therefore, independent efforts to monitor and analyze the space situation are being made by a very large list of countries. In Russia space surveillance data of space objects at high orbits are collected by large cooperation of optical telescopes and complexes which includes observatories of Roscosmos, institutes of Russian Academy of Sciences, few industry organizations and the International Scientific Optical Network (ISON). ISON project coordinated by KIAM RAS was started in 2004 in order to fill up the Center on collection, processing and analysis of information on space debris (CCPAISD) of the RAS.

Currently ISON consists of 47 telescopes in 24 observatories that allowed to receive 6'352'920 measurements during 2017 (about 28% from common volume of data in the CCPAISD). These telescopes are divided in 6 groups: (1) standard GEO survey (14 telescopes of 20 – 50 cm apertures with FOV of 3.3 – 5.5 degrees); (2) extended GEO survey (5 telescopes of 18-cm - 19.2 cm apertures with FOV 7 degrees); (3) tracking of bright (brighter than 15.5m) GEO and HEO objects (10 telescopes of 18 - 25 cm apertures with small and moderate field of view); (4)

tracking of the faint objects (fainter than 15.5m) at GEO and GTO (8 telescopes of 36 – 80 cm apertures); (5) tracking deep space mission (4 telescopes of 50-cm - 100 cm); (6) search and photometry the asteroids. Survey subsystem (1) is single in Russia that cross all Earth longitudes and provides the complete surveys of Geostationary region in strip width of 18 degree with detection of all objects down to 15 – 15.5m. It provides the main stream of measurements for maintaining of the Russian catalogue of bright objects. Extended survey subsystem (2) was elaborated to support the activities of the KIAM/ASPOS OKP centre on conjunction analysis. Its telescopes provides multiple view of GEO per night obtaining long measuring arcs up to few hours for all GEO-objects down to 14 – 14.5m. Therefore such surveys allows to determine more accurate orbits for 90% bright catalogued GEO objects for conjunction analysis procedure. Importance of tracking subsystem for bright objects (3) is that it provides more accuracy measurements during observations of pairs of approaching objects to improve its orbits for conjunction analysis. The quantity of such telescopes for accuracy tracking will be gradually increased. Unique benefit of the tracking subsystem of the faint objects (4) is that the 80-cm telescope K-800 at peak Terskol having large field of view (55') provides the statistical data on the small unobservable fraction of space debris at GEO to verify the Russian space debris population model at high orbits. Moreover first 40-cm telescope DIN-400 of new series will start operations soon in Nauchniy to provide more accurate measurements for faint debris. It uses all hardware methods to improve the accuracy of measurements - high resolution, electronic shutter, built-in in CMOS camera GPS-receiver. Other telescope, 50-cm ORI-50 with field of view as 2.5 degree in Andrushivka is carrying out the local survey of GEO to detect both known and unknown faint debris fragments. Such methodology seems to be important to remove currents instability cataloging the faint GEO-objects (number of fragments is highly variable with amplitude of 250 - 250 objects every 2.5 months, thus 50-60% of the known population is regularly lost).

Astrometry and Photometry of Satellites and Space Debris at the ISON-Castelgrande Observatory

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Keywords: astrometry, photometry, satellites, space debris, asteroids

In October 2017 optical observations of satellites and space debris were successfully started at the ISON-Castelgrande Observatory in South Italy, in the scope of the CastelGAUSS Project. The aim is to study physical characteristics of satellites and space debris and to collect their positional measurements for orbit determination and conjunction analysis. Currently in use is a custom-built 22 cm aperture telescope with 510 mm focal length on a Skywatcher EQ-6 Pro mount, with a 3056 px FLI MicroLine 9000 CCD (4° FOV), inside a 3-m Scopedome cupola; the entire setup is operated by the FORTE software package; observations can be performed remotely and in automatized mode. Successfully tested unattended alert observations of optical GRB afterglows will set an example for a similar technique in urgent tracking of newly discovered artificial space objects. Astrometric observations are of two modes: tracking – for selected objects, and survey – for selected sky areas. On clear winter nights, up to 300 different space objects were successfully observed. In tracking mode the faintest apparent magnitude of a space

object reached so far was 17.1 mag, in survey mode – 15.5 mag. Thanks to open horizon, observations are possible even at 1 degree altitudes. The workflow of photometric observations is still in development, but first results for satellites and asteroids have clearly shown definite progress and the applicability of the available setup for this task. The objective is to develop a semi-automated photometry pipe-line. Obtained images can be processed both manually and automatically either during or after the observation by the APEX software package, which is coded mostly in Python, thus having the advantage of using third party modules for astronomy tasks, and it is a fully developed pipe-line providing complete image calibration, astrometric and photometric reduction, automatic object detection and identification, and many other features. Positional measurement accuracy is 1–2 arcseconds. Observation scheduling and orbit determination are done at KIAM conjunction analysis centre, and calculated orbits are stored in a database maintained there. ISON-Castelgrande Observatory is a part of a larger International Optical Scientific Network (ISON) of observatories coordinated by KIAM. Observation techniques tested and results obtained in Castelgrande will surve other ISON observatories as an example. Installation of a 35 cm telescope for observations of faint objects is planned in the nearest future.

New Orbit Estimation Algorithms and Their Analysis in Difficult Observation Conditions for UN ORT Data

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Keywords: Debris, Detection, Iterative Weighted Least Squares Method, Orbit Determination, Orbit Parameters Estimation, Short-Arc Tracks Identification, Tracking, UN ORT

Estimation of orbits of near-Earth space objects with telescopes involves sparse data, i.e., the observations are collected only for a small fraction of the object's orbit revolution and the time-separation between successive observations of the same object can be very large. The challenge is to estimate orbit parameters for a single track and then to improve this estimate based on fusing several tracks. Since the objective function has multiple extremes, as a rule, the classical iterative weighted least-squares estimation method for finding the estimate of orbital parameters converges to one of the local minima. This makes it impossible to use the conventional least-squares estimation method for estimation of orbital parameters based on several (e.g., two) tracks that are significantly separated in time.

In this talk, we will present two key statistical algorithms for determining orbit parameters of near-Earth space objects – an efficient algorithm for the initial determination of an orbit based on a single optical track and a novel algorithm of estimation of orbit parameters based on two time-separated tracks. These algorithms allow us to calculate both an estimate of orbit parameters and a covariance matrix of estimation errors even for extremely short tracks obtained during two nights separated by several days without any a priori information about orbit parameters. The developed software that applies these algorithms and allows for estimating the

orbital parameters of near-Earth space objects by optical measurements in real time was tested on data obtained from the University Network of Optical Robotic Telescopes (UN ORT). These data include tracks of 20-30 second duration separated by time gaps up to two weeks and contaminated by anomalous errors of measurements. The results of data processing demonstrate very high efficiency of the developed algorithms in difficult conditions. The experiments also show that the developed identification-estimation algorithms guarantee reliable orbit estimation of unknown space objects even for highly separated tracks and that fusion of two tracks increases the precision of the orbit estimation dramatically compared to the single track estimation. In fact, the estimation accuracy turns out to be close to potentially achievable.

Recognition of objects from images of an optical telescope

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Artificial space debris around the Earth is a threat to the space missions. Collisions of orbital objects is usually deadly, generate more debris and increase risk of new collision. It is important to detect and track space objects to determine their orbital parameters. This information is useful to avoid impacts with operational spacecrafts. Most debris are located at the low Earth orbit. This thesis presents technique of image recognition to detect LEO objects with optical sensors.

First part of this study is about preprocessing of typical telescope images. The preprocessing contains correction of sensor artifacts (such as nonuniform background and dead pixels), noise estimation and stars deleting method. It reduces image complexity and makes further recognition more stable and reliable.

The second part describes technique of detecting objects in preprocessed image. There are two different algorithms of object detection proposed. One is developed for recognition the point shape objects by series of images, which is preferably for detecting low angular rate objects. This case is common for high orbit objects, however the algorithm can be used for particular telescope orientation and specific low Earth orbits. Second one is developed to recognize faint streaks of relatively fast moving objects. The algorithm is enough sensitive to detect object's streaks with small signal-to-noise ratio. Sensitivity properties of developed method makes prospective to detect small objects, which are invisible for radar based systems. After further development and testing, the algorithms will be ready to be implemented in space debris monitoring system.

An overview of modern numerical methods for ballistics

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In the modern world, more and more cosmic bodies appear on Earth's orbit. To determine their orbits and the position of these bodies after several turns, calculations of their trajectories are necessary. By themselves, ballistic problems have been solved for a very long time, but only recently there was a need to carry out these calculations quickly. The task appears in the context of modeling spacecraft groupings and for determining the trajectories of objects in low orbit, since as a rule, the time to determine this trajectory is short.

At the moment, all the methods used can be classified into four broad categories. The first is the embedded Runge Kutta methods. Explicit methods are used, in which the difference in the Butcher table is found only in the line of weights. At each step of the trajectory, 2 solutions with different accuracy are calculated, the error and the next time step are determined from their difference. The most famous and used representative of this category of methods is the Dorman-Prince method 7(8).

The second category is Adams multi-step methods. The bottom line is to store the values of the positions in space and velocities for several previous points of the trajectory. Methods in this category are explicit and implicit. The most well-known and popular is the Gauss-Jackson method, which combines an explicit approach in the predictor and an implicit approach in the corrector. The disadvantage of the method is the inability to adjust the step.

The third category of methods is based on Gauss quadrature formulas. The most famous representative for ballistic tasks is the Everhart integrator. The difficulty is in the necessity of calculating the Jacobi matrix of the system and solving a nonlinear system of equations, but the methods for estimating the initial approximation to achieve quadratic convergence of the Newton method and methods for determining the time step by estimating the residual term of the interpolation was developed.

The last class of methods appeared relatively recently - these are BLC-IRK methods. Their main idea is that for certain functions, in which the Fourier image is a function on a finite support, a system of orthogonal polynomials can be chosen, the zeros of which are more or less evenly distributed along the integration segment. For this system of polynomials, the Gauss generalized quadrature formula is defined. The beauty of the method is that each node can be determined separately from the others, and as a result, it can be parallelized on the GPU.

A feature that unites these methods is that all of them are aimed at clarifying and accelerating the solution of the equation as a differential equation, however, it is necessary to add to them the redefinition of the right-hand side.

Optimal spectral range determination for the small satellite onboard camera for remote determination of the geostationary space debris physical properties

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Keywords: space debris, threshold monochromatic sensitivity, infrared channel, spectral density, radiation flux, emissivity, photometric measurements, spectral range, small satellite

Three parameters: the temperature T, the emissivity factor ε and the size d of the space debris object (SDO), can be determined from the three fluxes of their radiation, registered in three corresponding spectral subbands with an optical digital camera. Subbands must be wide enough that the difference in registered fluxes would exceed the threshold sensitivity of the optical digital camera, and the chosen overall spectral IR band must be sufficiently narrow for the emissivity factor of SDO to be considered constant.

On the basis of modeling of the reflected from the object solar and its own radiation fluxes, rational IR subbands that provide maximum difference between registered fluxes are defined. Assuming that the error in photometric magnitude measurement is ~0.01, the errors of the determination of T, ε, d are calculated and minimal SDO size that allows for the determination of these parameters with an optical digital camera with set threshold sensitivity is determined.

A rational spectral interval $\delta\lambda \sim 3.6$ μm - 4.5 μm of the onboard optical camera is determined and substantiated for remote determination of physical properties of space debris objects of ~1.5 meter in size with small reflectivity at a threshold monochromatic sensitivity of the onboard camera ~1800 μJy and the observation distance of ~ 5·103 km.

Student Contest

Proposed system design idea of collection and safe disposal of small space debris

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Keywords: small size, space debris removal, space debris collection, flexible mechanics, hyper velocity

With Lower earth orbit containing majority of space debris ever increasing number of space junks ranging in sizes causing unwanted hindrance in space travel. Biggest problem is capturing of small objects from sizes few inches to meters thick. It is not beneficial to shoot nets or harpoon at every single small debris. My design will be able to collect debris on its path while travelling in the desired orbit and maneuvering when ever required to avoid collision. The design has space for small satellites for maneuvering and charging the system and all the basic components needed to function for desired time. Once targets identified, it will be directed toward the space debris with help of on board computer simulation shows promising results with the deployment of chute and collection of space debris. The chute will contain three layers with each layer having desired thickness. The distance between each layers ranging from 10-25 cm each. This will help in reducing the speed of the object. The system is in three stage deployment. Once collection capacity of space debris is achieved by the system then it can be towed to the altitude of atmospheric drag at the desired re entry point thus burning of debris safely and effectively. This article does not assume prior knowledge about the idea, but it contains extensive research available on the idea in how to remove space debris in a efficient and beneficial way.

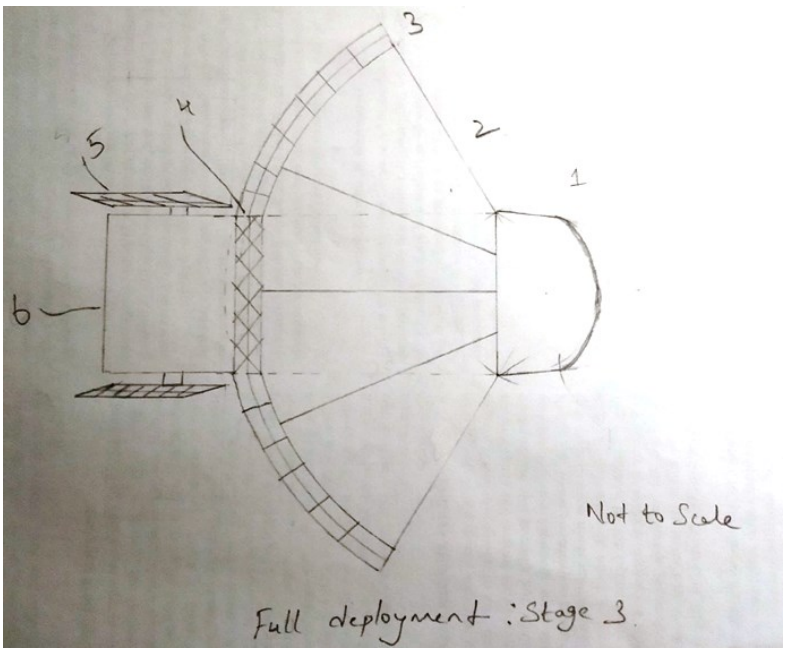

Fig. 1

Simulation of radio link operation using adaptive coding modulation

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Keywords: Satellite communication, Atmospheric attenuation, Radio link "spacecraft – station", Signal-Code Construction

Applying of Adaptive Coding Modulation (ACM) in the data transmission from a spacecraft to an earth station allows best uses of channel resources compared to the most commonly used Constant Code Modulation (CCM), and it allows for an increase bandwidth of radio links used for remote sensing systems.

The operation of two systems were compared, taking into account the attenuation of signals in the radio link. The model was applied using the recommendations of DVB-S2 [1]. The radio link with the feedback (figure 1) were simulated by comparing current SNR at each time interval and the required SNR value, providing the signal reception with a given BER to transfer the parameters of the most suitable Signal-Code Construction (SCC) to the next transmission interval.

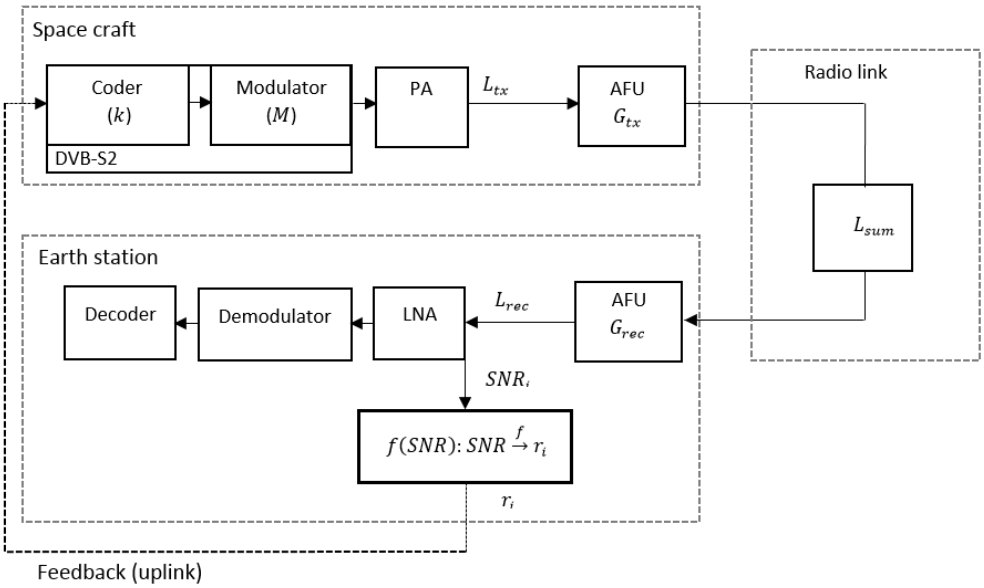


Fig. 1 General framework of the radio line "spacecraft – station" (PA - Power Amplifier, AFU - Antenna - Feeder Device, LNA - Low Noise Amplifier)

In the model, the delay of signal propagation in outer space $t_{\min}$ = 250 ms, and it determined the minimum interval for the parameters to be rearranged. The model uses SNR distribution corresponding to SNR changes during the passage of the simulated cumulonimbus cloud. The amount of potentially lost information (V) is calculated by the formula (1), where W = 1300 MHz is the bandwidth of the geostationary satellite Ka-Sat, T corresponds to the total time at which SNR value was less than the threshold.

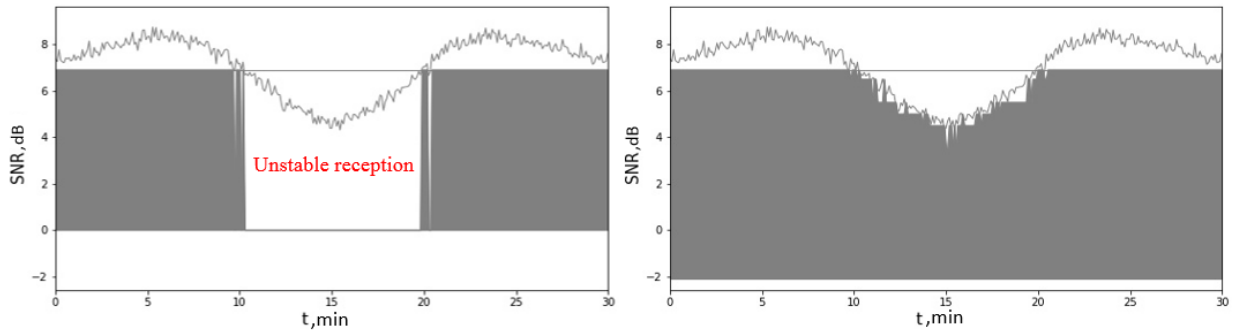
$$V = \sum_i \log_2 M_i \cdot k_i \cdot T \cdot W \tag{1}$$

where M_i, k_i are a modulation rate and a code rate in i interval,

W is the bandwidth of the transmitted signal [MHz],

T is the total time of unstable reception [s].

The results of two operations are shown in the figure 2. The initial spectral efficiency was $r_1 = \log_2 M_1 \cdot k_1$ = 2. The operations were simulated for a time interval of 30 min, and the sharp decrease in the SNR value was programed from 9 to 20 min as the attenuation of the signal, which led to communication interruption in CCM operation. In this case, T_{CCM} = 9.78 min, and V_{CCM} = 1524.9 Gbit. For ACM operation T_{ACM} = 58.9 s, and V_{ACM} = 132.3 Gbit, which is significantly less than during CCM operation.



a) b)

Fig. 2 a) Model of the radio link operation in CCM mode with SCC (M = 8, k = 0.67) at t = 6 s b) Model of the radio link operation in ACM mode (the desired spectral efficiency corresponds to M = 8, k = 0.67) at t = 6 s.

The figure 3 demonstrates the changes in losses ΔV and ΔT depending on Δt adjusted to linear scale for ACM. For instance, switching Δt from 0.25 s to 4 s, T and V increased by 1.86 s and 3.36 Gbit respectively. It is worth noting that Δt includes the delay of the signal coming from a spacecraft, a delay of transmitting the control signal to a spacecraft and a switching time of SCC, determined by the technical implementation of an onboard equipment of a transmission path.

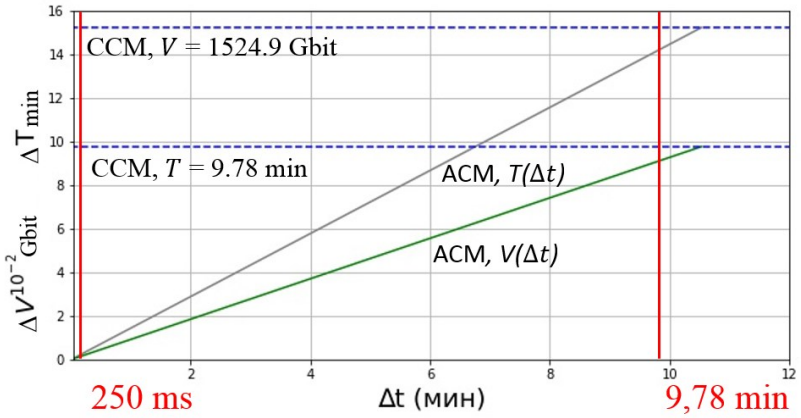


Fig. 3 Changes in the losses adjusted to linear scale for ACM

The results numerically confirm the importance of ACM implantation in the signal transmission path to prevent from stoppages and attenuations of different nature, the duration of which exceeds the interval time for rearranging the parameters of the transmitting equipment.

References

1. Digital Video Broadcasting (DVB). Implementation guidelines for the second generation system for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications. Part I (DVB-S2) // DVB Document A171-1, March 2015

Research and analysis of the defective structure of a metal sample after tensile tests to determine the properties of the material

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Keywords: X-ray tomography, strain field, tensile tests, plastic deformation

To reduce the mass of the spacecraft design during operation, plastic deformation of some structural elements is allowed. The safety factor of materials must be determined experimentally. The paper proposes a technique for the experimental determination of the magnitude of plastic deformations in a sample.

Currently, three methods are being used to reconstruct the displacement field: VIC-3D [1] and the method of speckle interferometry [2]. The methods restore the displacement vectors on the outer surface of the sample and do not determine the displacement of the inner points. The authors of the work [3] investigated the samples with the particles inside. The particles were visible in the tomographic study, the movement was determined relative to these particles. The problem is that the number of such particles is small and because of their presence, the material can be considered composite.

In this paper, we study the plastic deformation of the steel wire samples using the tomography method. A method for restoring the displacement field after the plastic deformation is proposed.

The experimental wire had thread-like defects parallel to the axis. The defects occurred during manufacturing. During the test and after the destruction of the sample, the defects did not disappear and did not leak. A sufficiently long defect after the destruction of the sample may begin in the cylindrical part, continue in the neck with a curvature, and end at the point of rupture. In fact, the samples practically did not have so long defects, however, there were a large number of short ones.

The displacement of the defect point along the radius can be calculated as the difference of the distances between the sample axis and the points at the beginning and end of the defect.

It can be assumed that in the cylindrical region the defects are not radially displaced. Therefore, the defect moves from the cylindrical area to the field moving in the neck area, then the defect from the restored area restores the field moving to the next one, and so the field of movement moves back to the point of rupture. Also, there can be found the defects that start in the area with the restored displacement field and continue into the area with unrestored.

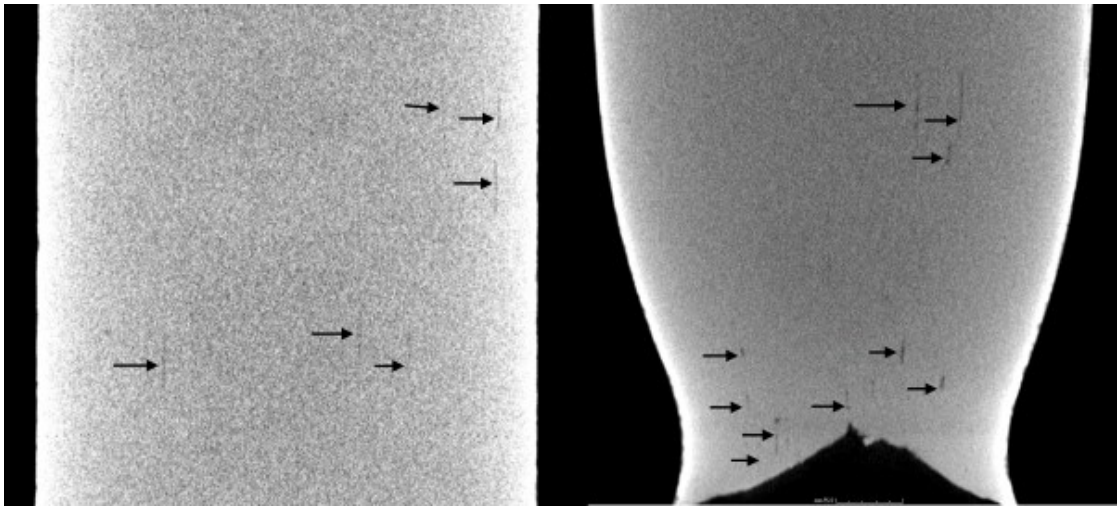

Fig. 1 Sample before and after destruction

References

1. Т.В. Третьякова Особенности использования программного обеспечения VIC-3D, реализующего метод корреляции цифровых изображений, в приложении к исследованию полей неупругих деформаций//Вычислительная механика сплошных сред. – 2014. – Т.77, №2. – С. 162-171

2. С.А. Баранникова, М.В. Надежкин, А.Г. Лунев, В.В. Горбатенко, Л.Б. Зуев Закономерности локализации пластического течения при электролитическом насыщении водородом ОЦК-сплава железа//Письма в ЖТФ, 2014, том 40, вып. 5, - С. 51-58

3. Philip J. Withers, Michael Preuss Fatigue and Damage in Structural Materials Studied by X-Ray Tomography//Annu. Rev. Mater. Res. 2012. 42:81–103

The assessment of operational capability of the space-based hyperspectral complex (HSC)

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Keywords: operational capabilities of remote sensing systems, hyperspectral images, simulation modeling, thematic processing, assessment of forest parameters

Purpose of the paper: to develop a method to assess an operational capability of hyperspectral complex in solving of thematic problem and test reliability of its work.

Tasks:

1. To develop a method of assessment operational capability of space-based hyperspectral remote sensing systems.

2. To provide a test calculations via the method.

3. To check reliability of the test calculation.

To assess an operational capability of hyperspectral complex was developed a statistical model. The model accepts as input data the parameters of a certain thematic problem and the parameters of the remote sensing system used to solve the problem. The concept of the model includes simulation the movement of Earth remote sensing satellites in orbit, modeling of an area of interest (AOI) of complex shape and its separation into different parts – segments – with a given accuracy, imitations the scanning of remote sensing instruments of individual segments of the AOI, considering cloud cover and solar zenith angle upon observation, calculation of indicators that characterize the operational capability of the remote sensing system.

The thematic problem of forest taxation in Valuisky region of Belgorod oblast of the Russian Federation was selected to testing of the methods work. In the model the test problem was solved by using of scientific equipment «Hyper-spectrometer»

(SE-HS). Figure 1 displays the area, obtained from the satellite, for which the test problem is going to be solved.

Test calculation for the selected AOI were performed. The results of test calculation confirm the reliability of the model.

Is planned that the method will be used in mission design for the astronaut operators of the SE-HS and the planning of experiments on the study of Earth from space in future projects of the “ELFOX” laboratory.

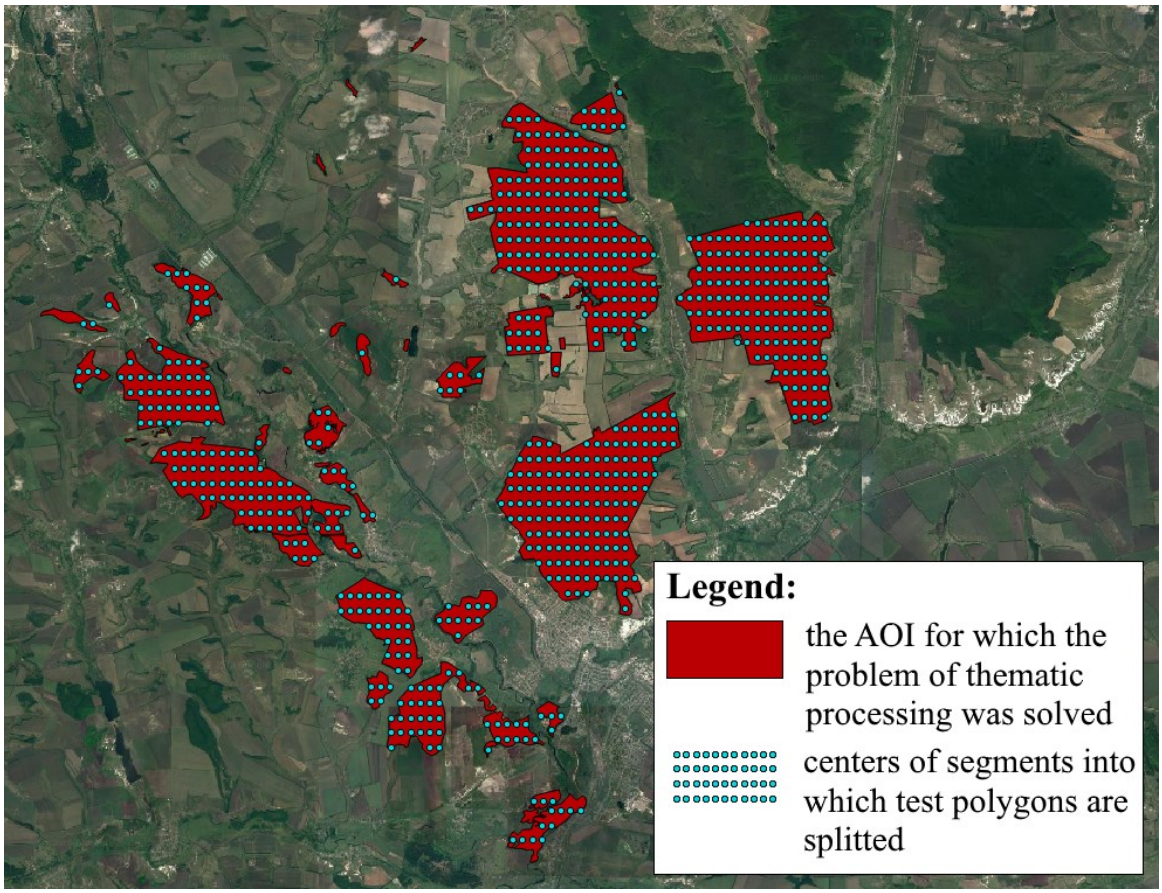

Fig. 1 Satellite image of Valuysky region of Belogorod oblast of the Russian Federation

Reflector and actuators for the mechanically reconfigurable space antenna

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Keywords: Mechanically reconfigurable antenna; piezo-driven actuator; honeycomb sandwich structure

In many applications of satellite communication, such as television broadcast, Internet access, and confidential communication, the shaped beam is used to increase efficiency and reduce the interference. Usually the shaped beam is reflected by the shaped reflector of satellite to have desired coverage over a geographical areas on the earth. A mechanically reconfigurable space antenna is, thus, a combination of several shaped reflectors and could cover several service area during the orbit lifetime. It gives an advantage of replacing several satellites with shaped reflectors by a single satellite with mechanically reconfigurable antenna. The mechanically reconfigurable antenna consist with reconfigurable reflecting surface and a group of actuators. And the actuators restraint the reconfigurable reflector to reshape for different service area.

Although several simulation studies regarding different types of mechanically reconfigurable antenna have been performed in the past few years, the design and experiment are few because the difficulty in development of deformable reflector and high push-to-weight ratio actuator with high resolution.

In this work, a mechanically reconfigurable antenna system was developed that has multiple arbitrary deformation modes and retains shape on power-off. The reflector has a smooth surface that is mechanically adjusted by an actuator array. We demonstrated that the carbon fiber laminated with aluminum honeycomb sandwich structure can be used as the reconfigurable surface. A linear and a rotary

piezoelectric actuator by means of inchworm motion were proposed for the reshaping and pointing control of the antenna. Both of the actuator were designed with large stroke, high load capacity (400 N/ 250 Nmm), and self-locking ability. The linear actuator was used in the actuator array to reshape the antenna, and the rotary actuator is going to use in the pointing control of the antenna. Finally, verification of shape control of the reflector was demonstrated in experiments.

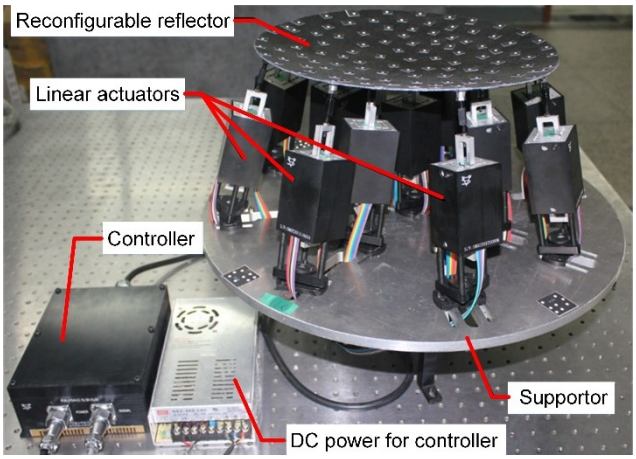
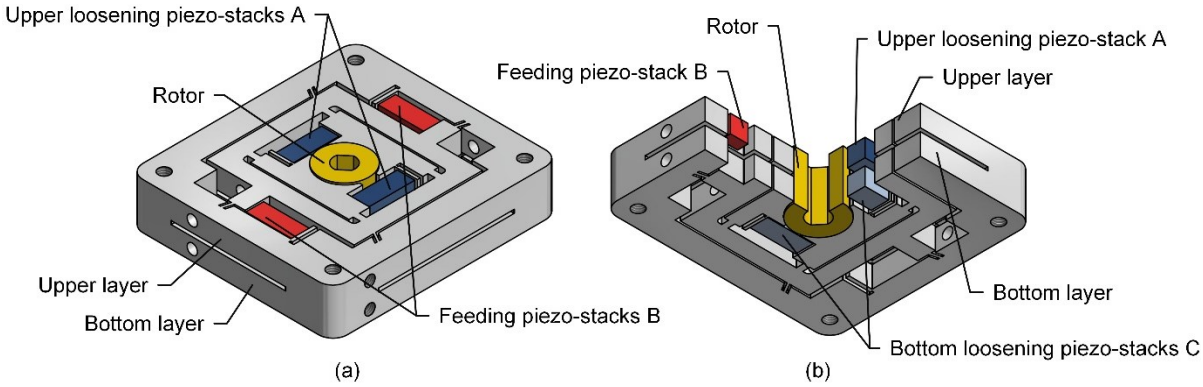


Fig. 1 Prototype of the developed mechanically reconfigurable antenna



(a) Oblique view of rotary actuator (b) Section view of rotary actuator

Fig. 2 Designed piezo-driven rotary actuator

Lightning detector for small science satellite

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Keywords: remote sensing, lightning detector, ISS, small satellite, high-speed camera, low earth orbit, detection of lightning flashes

The article describes the main problems of creation of lightning detector for space satellite. This device is designed to detect lightning flashes from the board of low-orbit satellite: small science satellite or the ISS. The purpose of work is determination of key characteristics of this scientific equipment and modeling of its work.

Registration of lightnings from the orbit is very difficult challenge. It needs to detect rather dim short-term flashes against the background of bright clouds. This generates the following hardware requirements:

* High aperture ratio of the lens

* High quantum efficiency of the photodetector and large pixel size

* The problem of including a narrow-band interference light filter into the optical scheme

* Availability of high-speed methods and algorithms for image processing

The report describes these aspects in detail.

The requirement of high aperture ratio of the lens gives rise to the problem of optimizing the mass-dimensional characteristics of the camera. In addition, the lens must combine this characteristic with a large field of view of 2w = 78,5°.

The high brightness of the background (clouds) produces high requirements for the photodetector. The report describes in detail the choice of the photodetector for

the camera. The photodetector must have the frame rate of 1000 Hz and high sensitivity parameters.

One of the key problems is the need to create an optical scheme with an extremely narrow bandwidth of spectral transmission (1...2 nm). The center wavelength is 777.4 nm. The interference filter has a problem of the angle of a beam. The center of the bandwidth has dependence on the angle of beam. This effect can be disastrous. The report contains description of variants of possible optical schemes that minimize this problem. Also there is a detailed calculation of the energy parameters of the camera. Verification of calculations is carried out by computer simulation of the received images for various conditions of surveillance.

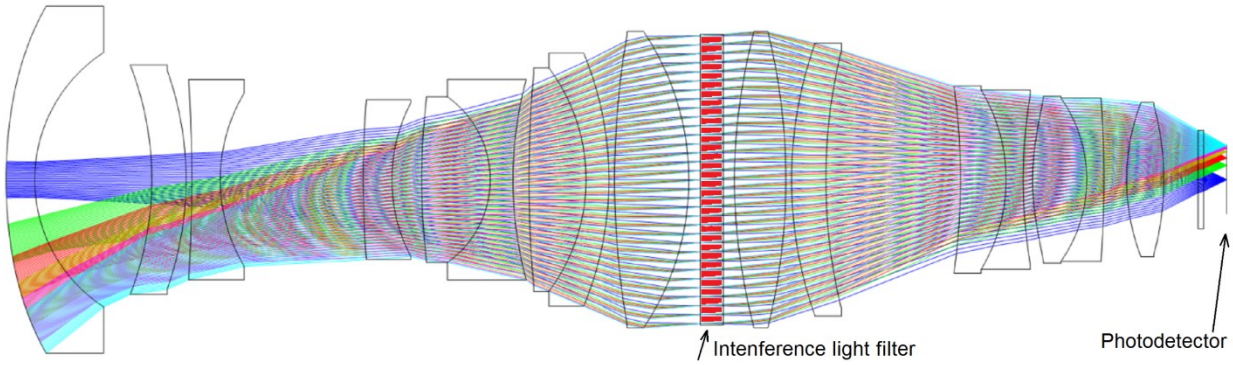

Fig. 1 Variance of lens system for the lightning detector

In addition to hardware solutions, the report describes the information processing algorithms. The key issues here are:

* Large information flow (1000 frames per second)

* Low signal-to-noise ratio requiring new solutions in inter-element imaging techniques

* The need to avoid false alarms of the camera caused by similar physical events (glare from mirror surfaces, bright lights, fires, light from night cities, fireworks, etc.).)

* The problem of coordinate reference

Calculations and modeling have established that the lightning detector with the specified characteristics can be created. It will provide detection of a lightning flash with a brightness of 5 μJ/(m^2*sr) with a probability of not less than 0.6.

The scientific equipment can be based on the ISS or small meteorology satellite. Its work will allow to accumulate new data on the time, brightness and geographical distribution of lightning flashes. The round-the-clock survey will useful to clarify climate models, build global maps of lightning activity and improve the accuracy of weather forecasts.

Strain-modulated initial stage oxidation of iron surface

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Keywords: Oxidation; Oxygen uptake; Prestrain; Phase transformation; Growth stress

Metal oxidation at high temperature is a critical issue in the aerospace industry, even subtle variations in the composition, structure and thickness of the oxide formed on metal components can significantly alter their chemical and mechanical properties and influence the durability. The influences of the external loading on the oxidation kinetics and oxide structure are crucial for understanding the initial oxidation of metal surface. Using the ReaxFF potential, we perform MD simulations about the initial stage oxidation of iron surface under various prestrains. A unique BCC-to-FCC transformation of Fe occurs as a consequence of oxygen atoms entering its tetrahedral sites. However, such highly ordered oxide structure transforms to the disordered under larger tensile prestrains. The evolutions of both oxygen uptake and internal stress are found to follow the direct logarithmic law. Moreover, larger tensile prestrain is favorable for the oxidation, leading to higher oxidation rate and larger internal stress gradient. Finally, the correlations between the oxide structure, internal stress and the oxidation kinetics are made and validated by analytical models. This work may provide new insights into the strain-modulated metal oxidation.

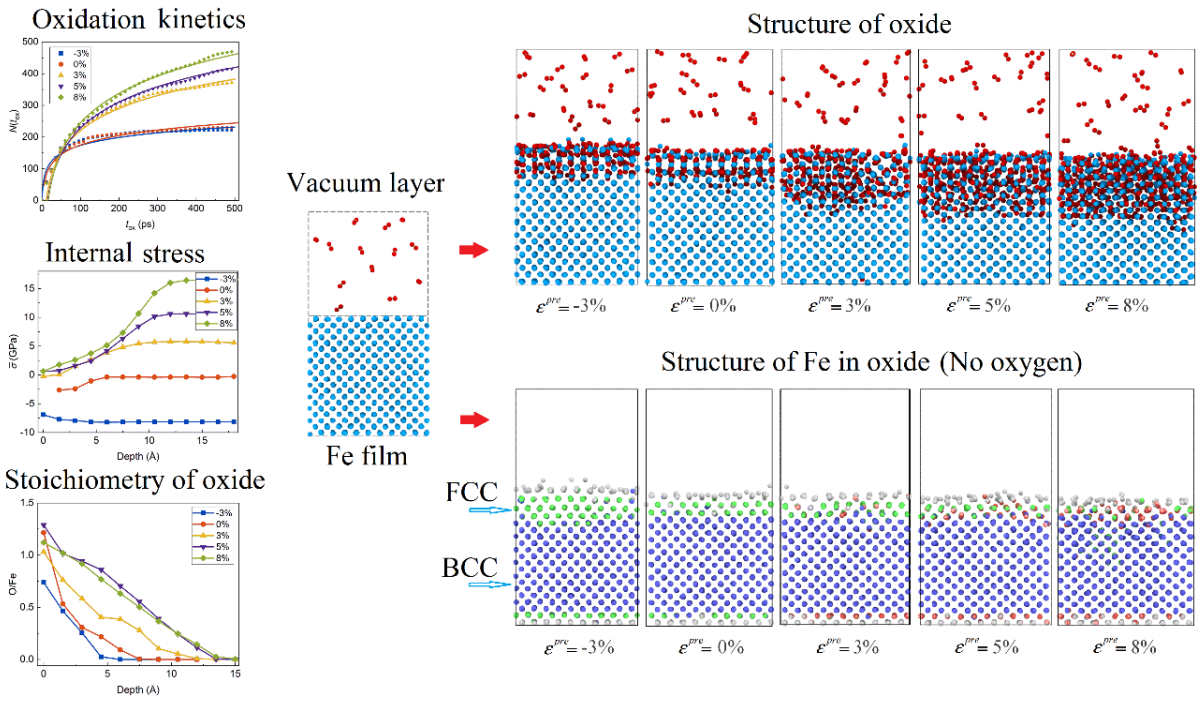
Oxidation kinetics
-3%
0%
3%
5%
8%
N(O_ox)
t_ox (ps)
Internal stress
σ (GPa)
Depth (Å)
Stoichiometry of oxide
O/Fe
Depth (Å)
Vacuum layer
Fe film
Structure of oxide
ε^pre = -3%
ε^pre = 0%
ε^pre = 3%
ε^pre = 5%
ε^pre = 8%
Structure of Fe in oxide (No oxygen)
FCC
BCC
ε^pre = -3%
ε^pre = 0%
ε^pre = 3%
ε^pre = 5%
ε^pre = 8%

Fig. 1

Demonstration of interferometric coronagraphy technology using a nanosatellite

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Keywords: cubesat, rotation shear interferometer, exoplanets

Methods of direct observation of exoplanets require high accuracy of the wave front. The main contribution to the error of the wave front is made by the atmosphere. Therefore, direct observation from the ground, even with the use of adaptive optics, severely limits the possibility of direct detection. Going beyond the atmosphere solves this problem.

In addition to the atmosphere, optics itself makes a significant contribution to wavefront distortions, both low-frequency (Comma, astigmatism) and high-frequency (PSD) aberrations. In this case, the use of a rotational shear interferometer, instead of the classical Lyot-coronagraph, allows reducing their influence on the final result. Demonstration and testing of this kind of technology in space conditions is one of the priorities of this project. In addition, such scientific problems as:

1. Search non transit and observation of opened exoplanets.

2. Direct observation of the vicinity of nearby stars (10+ ps)

3.H_α in the vicinity of young stars, supernovae, collimated jets, bright blue variables (LBV), quasars, galactic nuclei, spiral galaxies and other interesting structures.

In this project, the rotational shear interferometer makes it possible to achieve a contrast of 10^5 at angular distances close to the diffraction limit of the aperture used (40 mm) - 2 ’’.

Design

The payload in the form of a telescope-refractor, equipped with an interferometer of rotational shear is planned to be placed on a 1-U cubestate. The

layout scheme involves placing service systems (radio, power, orientation, and main computer) in half a unit. The other half is reserved for the payload (Fig. 2). Structurally, the payload is depicted in Fig. 2.

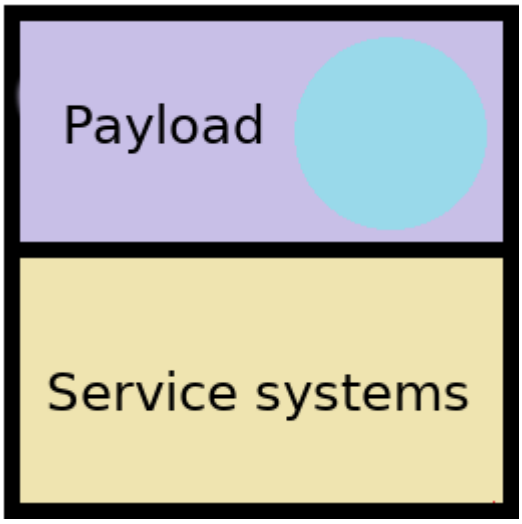

Fig. 2 Layout scheme

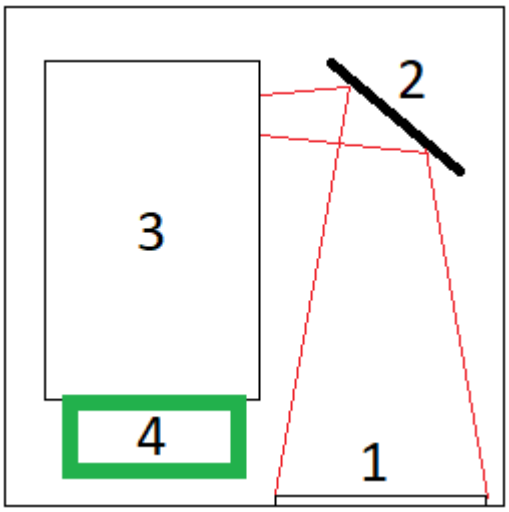

Fig 1 Payload(1 - lens, 2 - auxiliary mirror, 3 - interferometer, 4 – camera)

Measurement technique

For coronagraphic measurements, sub-second satellite positioning accuracy is required. With limited mass and energy budget, such positioning accuracy is difficult. However, a technique was developed that allows measurements to be carried out with inaccurate targeting of the object of interest. The targeting algorithm consists of the following steps:

Rough guidance using magnetic coils (10 degree accuracy)

Accurate targeting is performed using gyros. Using the planned star sensor and gyros, the accuracy of targeting will be about 1 arc minute.

It is obvious that this accuracy is not enough. However, under the action of various external and internal disturbances, the optical axis of the telescope will oscillate in the vicinity of the desired direction, as a result of which there will be moments in time when the axis will sufficiently coincide in direction. It is at such times that measurements will be taken.

The presented nanosatellite project will allow testing of new technology of coronagraphy in space conditions. Despite the small aperture, this project can conduct a number of scientific studies where high contrast is required at relatively small angular distances.

Poster Session

Methane-air flame under the alternating gravitational forces

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Keywords: Methane-air mixture, premixed combustion, microgravity, flame instability

The combustion processes under the alternating gravitational conditions is an important issue, especially for the application. Modern flying vehicles are used to operate both under the elevated gravity conditions and reduced. So the flame behavior, especially instabilities under the transition conditions, is influenced the engines efficiency. At present, most of the works [1, 2] are devoted ether to the flame characteristics under the reduced gravity, or — under the elevated, whereas the transition conditions could bring to the flame oscillations and even quenching. The present work is devoted to the modeling of the methane-air flame behavior under the alternating gravity conditions.

Numerical simulation was carried out by using a FlowVision software package [3]. A complete system of Navier-Stokes equations with RANS turbulence model k-ω SST for a viscous compressible gas was simulated. The equations of state of the components corresponded to the model of an ideal gas. To solve the system of linear algebraic equations, an implicit numerical scheme of the second order of accuracy without constraints was used. One-step global reaction model of methane combustion was used to simplify the modeling process. A conical nozzle was used as the burner, providing a uniform flow of velocity at the outlet section. The outlet diameter was equals to 15 mm. The change of gravitational forces was set using the table depending on the time. The results show the flame instabilities, which are exhibited through the flame front oscillations and separations of the plume parts.

After stabilization of the gravity at constant level, oscillations are damped. This work showed the possibility of numerical modeling of the influence of a variable gravitational field on a flame and future research will be aimed at studying the main characteristics of a flame under such an impact as well as the limits of steady burning.

References

1. Ross H. D. (ed.). Microgravity combustion: fire in free fall. – Elsevier, 2001

2. Krikunova A. I., Son E. E. Premixed Flames Under Microgravity and Normal Gravity Conditions //Microgravity Science and Technology. – 2018. – P.1-6

3. Aksenov A. A. et al. Flowvision: industrial computational fluid dynamics //Computer research and modeling. – 2017. – T. 9. – №. 1. – P. 5-20

Improving the accuracy of spectral mode estimation of light reflections from space objects by two-way Prony method

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Keywords: two-sided Prony method, digital signal processing, overdetermined system of Yule – Walker equations, spectral parametric estimation, Moore – Penrose inverse, weight vector.

The aim of the work is to improve the quality of spectral mode estimation for processes with a smooth change in the intensity of light reflections from space objects by the two-sided Prony method.

In the modern world, research on the detection and extraction of space objects (CO) of artificial and natural origin is one of the most important problems. Trends in the development of the space industry make it possible to fill near-earth space with satellites for various purposes in an arithmetic progression. Many of them have a lifespan of less than 5-15 years, depending on their type: geostationary, medium-altitude or low-orbit, which leads to littering of near-earth space.

Specialists from various branches of science and technology are involved in monitoring near-Earth space. The problems encountered are the definition of small objects in real time. One of the ways to solve this problem is to analyze the spectrum of changes in the brightness intensity from the observed CO, which can characterize the dynamics of its movement. [1].Spectral analysis of the reflected light signal, as will be shown below, makes it possible to significantly increase the informative component of astronomical observations, especially under conditions of a short time T for CO tracking [2].

Analysis of the spectrum of changes in the intensity of signals containing a small number of samples, parametric, as well as classical non-parametric methods, does not take into account the smooth change in signal power during the observation

time. An example of this would be CO tracking, which, passing near the zenith, has, as a rule, maximum brightness, and at low angles of place - minimal. Evaluation of the frequency of flickering of light reflections from a CO will allow you to diagnose its technical condition or to open the current view [3].Therefore, to improve the quality of the spectral analysis of the reflected TO light signal, it is necessary to use a technique that takes into account the fact that the process power has changed during time of observation T.

Let us present the results of observations of X for a space object coming through N various information channels in the form of the realization of a vector N-dimensional random process of finite connectedness:

$$\mathbf{X} = [\mathbf{x}_0, \mathbf{x}_1, ..., \mathbf{x}_t, ..., \mathbf{x}_{T-1}],$$

where $x_t=[x_{0,t}; x_{1,t}; \ldots; x_{n,t}; \ldots; x_{N-1,t}]^T$ — N dimensional vector's t-th time sample of the observation process;

$x_{n,t}$— the value of the t-th observation in the n th channel; n=0,1,…,N−1;

^{T}— transpose mark [4].

Under conditions of smoothly varying power and taking into account the fact of increasing and then attenuation of the signal, we will form a model based on X observations in the form of a modulation of the cosinusoid square signal (fragment from −90° to 90°). In order not to perturb this model, it is proposed to weigh the samples X by the weight vector wt, with the components:

$$w_{n,t} = \cos\left[\frac{\pi \cdot t}{T} - \frac{t}{2}\right]^2,$$

where $w_{n,t}$ — weighting factor of time samples.

Analyzing this expression, it can be stated that the weighting coefficients reflect the tendency to lose the estimate of the potential accuracy of the X samples of observations at a smoothly varying signal power. When taking into account the values of $w_{n,t}$, which form the vector w, the changes in the amplitude of the signal **X** during the time T of observations can be represented as follows: $\mathbf{Y} = \mathbf{XW}$, where **Y** — implementation of reflections from the observed object with weighting of **X**

samples; **W**=diag(w) — square matrix with elements of w vector on the main diagonal.

We will analyze the proposed method on the example of describing observations of an artificial Earth satellite «Iridium-83», in three (N=3) color ranges, observed from the Moscow area (54°68'N, 39°68'E).

Fig. 1 Flash of «Iridium-83»

The criterion for evaluating the effectiveness of the proposed technique for each of the R, G, B colors, consider the relative deviations ΔF of the estimated flicker frequencies $\hat{F}$ from the true frequency F:

$$\Delta F = \frac{\left| F - \hat{F} \right|}{F} \cdot 100\%.$$

Having calculated the relative error parameters of the estimated frequencies for R, G, B colors using the two-sided Prony method and averaging them, we obtain $\overline{\Delta F}_{\text{RGB}}$ =(ΔFR+ΔFG+ΔFB)/3=(11,8+7,3+7,3)/3=8,8 %. It should be noted that the relative error of the AP method exceeds 100%.

Thus, studies have shown that using the proposed technique it is possible to significantly (from 8.4 to 13.7 times) improve the quality of spectral mode estimates for processes with a gradual decrease (increase) in the intensity of light reflections from space objects, by taking into account the fact that the power changes signal during observations.

References

1. Диденко А. В. Исследование фотометрических характеристик геостационарных ИСЗ методом электрофотометрии: диссертация на соискание уч. ст. канд. физ.-мат. наук. Алма Ата, 1991. 122 с.

2. Андреев В. Г. Метод обнаружения сигналов от непрерывно излучающих вращающихся объектов // Вестник Рязанского государственного радиотехнического университета. 2011. № 3. Вып. 37. С. 23 26.

3. Андреев В. Г. Оптимизация моделей многомерных сигналов спутниковых навигационных систем // Вестник Рязанского государственного радиотехнического университета. 2012. № 2.— Вып. 40. С. 30 34.

4. Марпл-мл. С. Л. Цифровой спектральный анализ и его приложения: пер. с англ. М.: Мир, 1990. 365 с.

KDS – the new software package for the robotic optical observations

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Keywords: optical telescopes, space debris, asteroids, astrometry, photometry, robotic observations

The new software package for robotic observations is being developed for tasks of ISON project since 2017 and now it tests at two remote observatories: ISON-NM (Mayhill, USA) and ISON-SSO (Coonabarabran, Australia). The main goal for KDS software package is a fully automatic and seamless combination of observations of different type of targets: such as static astronomical objects, minor bodies of the Solar System (parsing orbits in MPC format), artificial satellites and space debris (parsing orbits in TLE and Russian "Form 200" formats). Besides these targets, KDS can works with astronomical alerts systems like GCN network (which provide near real-time information about gamma-ray bursts) and TNS network (work in progress, information about Galactic and extra Galactic optical transients like Novas and Supernovas). Program can analyze new unconfirmed moving objects on NEOCP page (Minor Planet Center) and carry out its follow-up observations. All dynamical targets can be observed with 2-axis tracking.

KDS can work in two different modes – linear and dynamical scheduler. In Linear or classical mode, software consistently performs observations targets from observing list (it may be are static or different types of dynamical targets). In dynamical mode KDS automatically ranging targets by many parameters, such as priority, visibility conditions, angular distance to Moon and Galactic equator and, of course, minimize time consumption for slewing and meridian flip (for German-type mounts).

The time-critical targets, like gamma-ray burst alerts, can interrupt the current observing task and proceed it observations immediately. Non time-critical targets, like optical transients of different nature, just adding to current observing list after

current target, in Linear scheduler mode, or include in target list with maximum priority in Dynamical scheduler mode. List of supported alert sources can be operatively extended.

Software package developing under OS Windows (x86 or x64 versions) and can use native or ASCOM drivers for mounts, CCD-cameras, focusers and filter-wheels. It provides full support for different type of weather stations and cloud sensors (Davis, AAG) and have flexibly configurable parser for using various type of unsupported devices. It is equipped with a friendly graphical user interface which support Windows XP and above (it's may be very useful for support of old hardware). GUI shows current scheduler information, weather data, current status and parameters of all connected equipment. The progress of the observing program shows in the console window. In addition, KDS can send information emails to the registered users.

In the near future, KDS software can become the core of distributed network with client-server architecture of fully robotic telescopes, which can interact with each other. For example, telescopes can exchange information about completed or aborted observing targets, current weather conditions, follow-up a newly discovered object.

During deployment of KSD package at ISON-NM and ISON-SSO observatories, this telescopes already made a several hundred thousand of astrometric measurements, discovered a dozen Near-Earth asteroids and 3 comets, carried out urgent observations of gamma-ray burst with response time less than 60 seconds.

Mid-IR heterodyne spectrometer based on fiber optics for planetary atmospheres observations (HISPAR)

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Keywords: atmospheres, spectroscopy, planetary studying, satellites, remote observation

We present a Heterodyne Infrared Spectrometer for Planetary Atmospheres Research (HISPAR) based on distributed feedback quantum cascade lasers operated in middle infrared region (MIR). The HISPAR instrument could be installed on meter-class infrared telescopes or on the satellites for remote planetary observations. The core features of the concept are compact design, utilizing a novel mid-IR fiber optical components, hot electron bolometer (HEB) as sensitive broadband mixer and dynamic local oscillator frequency locking using reference molecule absorption line. HEB is a very promising mid-IR heterodyne mixer due to ultimate noise performance and wide bandwidth. The target instrument characteristics are similar to modern heterodyne device MILAHI (Tohoku University, Japan). Cross-measurements with both heterodyne instruments could be conducted for data validation.

The key advantage of high spectral resolution in the analysis of the outgoing radiation spectra of planets is concerned with the capability to retrieve detailed information about composition, structure, and photochemical kinetics of their atmospheres. Ultra-high spectral resolution ($\lambda/\Delta\lambda \sim 108$) provided by a heterodyne detection of the infrared radiation allows for Doppler wind measurements at different altitudes. The most valuable problems to be solved are vertical temperature and wind profiles on Mars and Venus, integral and vertical concentration

measurements of minor constituents on Mars and Venus, wind and temperature on Titan. This provides information for heat balance and global atmospheric dynamics recovery, which is essential for comparison with 3D general circulation models.

Optical heterodyning is related to difficult optical alignment of received signal and local oscillator emission. Fiber-based technology in mid-IR could simplify heterodyne instrument optical scheme. For this purposes Tohoku University group develops hollow waveguide system for MILAHI, MIPT group develops chalcogenide fiber-optical devices in mid-IR region. Theoretical model for chalcogenide fused fiber couplers and experimental setup for its fabrication and characterization was developed in MIPT. Fiber couplers based on AsSe chalcogenide glass will be utilized in MIPT heterodyne spectrometer.

KIAM capabilities and solutions for SSA and space debris research

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Keywords: satellites, optical telescope, space debris, database, ballistic

Keldysh Institute of Applied Mathematics (KIAM RAS) is the leading academic Institute studying the problems of space debris and ensuring the safety of space flights. KIAM's database has been created in 2005 by the order of RAS for data collection of the ISON network including space object identification and accuracy analysis of received observations, orbit determination (OD) based on a numerical propagation, maintaining and daily updating list of orbits and scheduling of the ISON observations. The database keeps the archive of observations, orbits and related events. Since 2012 centre on conjunction analysis (CA) has started its operations by joint RAS/Roscosmos resolution under annual contracts. It provides the automatic screening and daily data transfer to MCC TSNIIMash (including on-demand requests) and the analysis of related events (launches, fragmentations, disposals to graveyard orbits). CA procedure is conducted not only for GEO objects but also for MEO orbits (which OD incorporates both ISON data and freely available laser ranges and GNSS products) and HEO objects which passes through these regions. In 2017 the KIAM's database collected 22.689 million observations in 2.647 million tracklets for about 6000 space objects at high orbits. The observational and orbital data from the KIAM's database is used for elaboration and verification of the statistical space debris population model.

Some nanomaterials for space technology

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Keywords: nanomaterials, self-healing effect, adaptive surface, nanotube, coating

At present, the development of the space industry requires new materials with special and sometimes unique physical and technical characteristics. Production of nanostructured and nanostructured materials is one of the priority directions of development of technologies for obtaining enhanced characteristics of functional materials. As a result of the activities of "Keldysh Center", the head organization of the rocket and space industry in the field of nanotechnology and nanomaterials for the development of new materials, coatings, systems, energy elements, a large amount of work on fundamental and exploratory research in the field of nanotechnology was obtained. On the basis of the obtained fundamental reserve, a number of nanostructured materials and devices for rocket and space technology products have been developed in order to improve their performance and expand their functionality. From the ongoing work and developed materials and devices that use the unique capabilities of nanomaterials, the following developments are noted:

1. Layered nanostructured composites with self-healing effect based on plastic borosiloxane matrices filled with reaction and reinforcing fillers. The concept of the developed materials is that each layer in the composite performs its specific function, and in the general system, the layered material is able to minimize damage and restore its original characteristics.

2. Adaptive thermoregulatory surfaces based on thin-gauge nanostructured amorphous-crystalline thermal drives. The developed adaptive temperature-regulating surfaces are capable of autonomously changing the coefficients of as (absorption of solar radiation) and ε (coefficient of thermal radiation) by changing the position of the plates (blinds) that form the surface of the spacecraft.

3. Sensitive elements of gas sensors based on nanocomposite structures from a mixture of metal oxides and multi-walled carbon nanotubes. Sensitive elements of gas sensors based on nanocomposite structures from a mixture of metal oxides and multi-walled carbon nanotubes.

4. Thermal barrier multilayer and gradient nanostructured high-temperature coatings based on compounds HfO2-Y2O3, La2Zr2O7, Gd2Zr2O7, etc. The coatings have been deposited by low pressure plasma spraying using effects of Prandtl-Meyer expansion fun.

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Satellite radio link with low power consumption

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This is a prototype of a radio link for a small satellite, which allows to conduct ground testing. Small satellite requires small transceiver with low power consumption. To achieve low power consumption and small size of the equipment, the FPGA holds both zero and intermediate frequency signal processing and firmware running on LEON3 processor.

We use the following technologies

- Modulator and demodulator based on one FPGA
- Use of intermediate frequency to raise sensibility of a receiver
- Zero and intermediate frequency signal processing on FPGA
- Antenna Diversity algorithm for up to 10 antennas
- Doppler effect correction in pass band of 200 kHz
- Convolutional encoding
- Hardware CRC-32 calculation
- Automatic gain correction AGC, PGA
- ESA PSS-04-105 compatible
- Running on LEON3 processor, SPARC architecture
- AMBA compatible Modulator and Demodulator modules
- Custom RTEMS 4.10 build
- Simulation on all levels (physical, modem, protocols)

The results are

Power consumption:

TX mode: 9 W

RX mode: 4 W

Power save mode: 0.5 W

Mass: 0.3 kg

Bitrate: up to 2 Mbit/s

Modulation: QPSK

Interfaces: CAN 2.0B, Ethernet, UART, JTAG, LVDS SPI

Turn-on time: less than 0.5s (fast wake-up)

Unmanned vehicles control

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Centralized control is a primary method to work with a group of vehicles. The control center sends the desired motion directions to every vehicle and takes all of them into account. The system is globally organized without any capability of independent behavior for a group member.

With truly decentralized control, every vehicle in a group interacts and synchronizes with other members while achieving its own goal. Such scheme allows both individual and collective behavior, just as well self-organization. This method was chosen for the application in real unmanned vehicles.

Application Area:

• Area search

• Organization by communication over long distances by means of retransmission

• Ground mapping with precise reference to global coordinates

• Control and patrol large areas

Interaction Laws:

Swarming behavior (as in bird flocks, fish schools, insect swarms). In 1987 Reynolds was the first who proposed the set of simple rules to describe it. Namely separation from each other, cohesion and velocity alignment. He successfully programmed and modeled them in computer 3D animation.

Formation flight. This term means forming a group of flying objects in the desired space (geometric) form. Initially it was used for naming a special composition form of airplanes in the flight mission.

Both of them were used to produce own vehicles interaction algorithms.

MIPT's Hyperspectrometer for ISS

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Currently, MIPT is leading the scientific and technical cooperation of space industry enterprises in Russia to create a hyperspectral research complex designed to be installed on an international space station and for carrying out topical studies of the underlying surface by a cosmonaut. MIPT is the only university in the country, and perhaps in the world, whose students participate in the work on the creation of a research and development complex intended for use onboard the ISS.

The main tasks of the planned experiments consist in obtaining and processing by the cosmonaut-researcher hyperspectral images of the earth's surface in various spectral channels of the visible and near IR spectral ranges in the interests of solving specific applied problems:

• Operative monitoring of fires and other dangerous phenomena

• Monitoring the current state of crops

• Development of methods for detecting the consequences of man-made disasters

• Analysis of hyperspectral images and preparation of training samples

• Recognition of natural and

man-made objects

• Work to control the indirect signs of possible climate change

• Study of the influence of spectral characteristics of equipment on the account of atmospheric correction and other scientific and methodological issues.

M-DLS laser spectrometer for EXOMARS-2020 landing platform

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MIPT takes part in the joint ESA-Roskosmos mission ExoMars, targeting studies of the Red Planet's capabilities to host biological activity. The MIPT's contribution to the second stage of the mission, implying sending a research rover to Mars, is the multichannel diode laser spectrometer M-DLS developed and manufactured in cooperation with Space Research Institute RAS. Phystech unit responsible for the instrument development is the Laboratory for Applied Infrared Spectroscopy (AIRS) lead by Alexander Rodin.

Science objectives

Continuous observations of chemical and isotopic composition of the Martian atmosphere near the surface during platform's lifetime.

Implementation

• High-resolution, highly sensitive tunable diode laser absorption spectroscopy (TDLAS) combined with optical path enhancement by integrated cavity output spectroscopy (ICOS)

• Molecular absorption measurement at 2.6÷2.9 μm

• Search for diurnal, seasonal and sporadic variations of H_2O, HDO, $H_2{}^{18}O$; CO_2, $^{13}CO_2$, $CO^{18}O$, $CO^{17}O$

• Atmosphere gas sampling via MGAS instrument

European contribution

GSMA/CNRS (France) – laboratory tests, instrument characterization, data treatment.

Molecule	Wavenumber, cm^{-1}	Expected abundance	Concentration measurement accuracy
CO_2	3580.786	~ 95%	~ 0.2%
$^{13}CO_2$	3580.843	~ 95%	~ 0.2%
$CO^{18}O$	3580.907	~ 95%	~ 0.2%
$CO^{17}O$	3580.970	~ 95%	~ 0.2%
H_2O	3764.59913	~ 200 ppm	< 0.2%
$H_2{}^{18}O$	3765.09081	~ 200 ppm	< 2%
HDO	3764.87629	~ 200 ppm	< 2%

Laboratory and numerical simulation of drop flow for droplet cooler-radiator

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Nowadays, in cosmonautics appear new problems, for example, long-distance space travel and cheaper satellite delivery to the required orbits, the solution of which requires the development of fundamentally new technologies.

On June 22, 2010, by the order of the President of the Russian Federation No. 419-rp, a grandiose project was launched - Development of a transport-energy module (TEM) with a megawatt-class space-based nuclear power propulsion unit. The power of such a propulsion system should be tens and hundreds of times greater than the power of its predecessors.

The creation of new technologies required the cooperation of a large number of institutions, including the MIPT. We were given the taskon modeling a promising cooling system. The removal of heat in space can be accomplished only by radiation. Modern cooling systems are huge and have a heavy weight. A new solution was required, and it was found in the form of a droplet-emitter cooler - a system whose coolant will circulate not inside the spacecraft, but in open space.

The coolant drops under the action of solar radiation, the particles of the ionosphere and the plasma of their own external atmosphere are charged and begin to scatter. It was especially important to correctly assess the effect of scattering and figure out how to compensate for it. For this, the MIPT team created a special set of programs that takes into account most of the physical effects acting during flight in outer space. To confirm the calculated results in the laboratories of MIPT, a large cycle of experimental and analytical testing was carried out.

The obtained results prove that the scheme with an open drip cooling system is more efficient, and the expansion of the droplets can be compensated. In the next two years, MIPT, together with Roscosmos enterprises, will have to work out a new cooling technology in a space experiment.

Low-cost reliable onboard computer

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Low tolerance to radiation is known to be the main issue of electronics based on industrial grade components. We have designed a prototype of low-cost and reliable onboard computer (OBC) for low Earth orbit (LEO) missions. The computer architecture is based on LEON3FT processor core implemented inside FPGA. The OBC utilizes special multichannel guard system to prevent impact of destructive Single Event Effects (SEE) such as Single Effect Latchup (SEL). Total Ionizing Dose (TID) tests performed on our OBC showed the level of parametric degradation of the most susceptible components to be above 10 krad, which would allow to operate in LEO for more than 5 years.

Full cycle of tests and experiments was performed on OBC for confirming the quality. The list of conducted tests:

– X-ray control for checking quality of manufacturing

– Functional tests

– Thermocyclic tests

– Vacuum tests

– Vibration tests

– Radiation tests

Conducting functional tests during thermocyclic testing and vacuum testing allows simulating onboard operation process in close to orbital conditions and shows weak points in design and emphasizes the right solutions.