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SIMULATION OF THE INTERACTION OF SPACECRAFT WITH THE RAREFIED IONOSPHERIC PLASMA

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Principles of simulation of the physical-chemical and electromagnetic interaction of a spacecraft with the near-satellite environment and principles of probe diagnostics of rarefied plasma flows onboard a spacecraft are stated. Equivalence criteria are formulated for the interaction of a spacecraft with the near-satellite environment and hypersonic rarefied plasma flows on dedicated setups, in particular on the plasmaelectrodynamic setup of the Institute of Technical Mechanics of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine, which has the status of the National Patrimony of Ukraine. The features of spacecraft interaction with the near-satellite environment were studied along the following three lines:

- degradation of the materials and performance characteristics of spacecraft components in a long-term orbital service:
- magnetohydrodynamic interaction of a spacecraft with hypersonic rarefied plasma flows;
- probe diagnostic of rarefied plasma flows onboard a spacecraft.

Along the first line, a calculation-and-experiment procedure was developed to evaluate the power decrease of spacecraft silicon solar batteries under long-term (~ 10 years) exposure to the space factors and the near-satellite environment in circular orbits. Principles of accelerated life tests for the resistance of spacecraft polymer materials to long-term exposure to atomic oxygen flows and vacuum ultraviolet radiation were developed. Simultaneous exposure of polymers to atomic oxygen and vacuum ultraviolet radiation results in the synergic effect of mass loss by materials that contain a monomer of the $(CH)_n$ group.

Along the second line, models were formulated for magnetohydrodynamic interaction in the magnetized spacecraft – ionospheric plasma system. It was shown that the interaction of a ~0,8 – 1.5 T magnetic field of a space debris object (in particular, a spent spacecraft) with the ionospheric plasma produces an electromagnetic drag force sufficient for removing it to a low orbit followed by its burn-up in the dense atmosphere.

Along the third line, procedures were developed for ionospheric plasma probe diagnostics using onboard instrumentation that includes mutually orthogonal cylindrical electrical probes and a two-channel neutral-particle detector. It was shown that this instrumentation with the use of proprietary output signal interpretation algorithms and procedures allows one to locate sources of space-time disturbances in inospheric plasma parameters caused by natural and technogeneous catastrophic phenomena on the subsatellite track.

Keywords: *spacecraft, ionospheric plasma, simulation, interaction, degradation, drag orce, diagnostics.*

1. Kreinin L. B., Grigoreva G. M. Solar batteries under exposure to space radiation. Outcomes of Science and Technology. V. 13. Space Research. Moscow: VINITI, 1979. 128 pp. (in Russian).

2. Raushenbakh G. Handbook on Solar Battery Design. Moscow: Energoatomizdat, 1983. 360 pp. (in Russian).

3. Shuvalov V., Kuchugurnyi Yu., Lazuchenkov D. Modeling the interaction of spacecraft with plasma flow, electromagnetic radiation, electric and magnetic fields in the Earth’s ionosphere. Space Research in Ukraine. 2018-2020. O. Fedorov (Ed.). Kyiv: Akademperiodyka, 2021. Pp. 29-31.

4. Shuvalov V. A., Pismennyi N. I., Reznichenko N. P., Kochubey G. S. Simulation of the physicochemical effect of atomic oxygen of the Earth’s ionosphere on polymers. High Energy Chemistry. 2021. V. 55. No. 1. Pp. 52-58.
https://doi.org/10.1134/S0018143921010124

5. Shuvalov V. A., Reznichenko N. P., Tsokur A. G., Nosikov S. V. Synergetic effect of the action of atomic oxygen and vacuum ultraviolet radiation on polymers in the earth’s ionosphere. High Energy Chemistry. 2016. V. 50. No. 3. Pp. 171-176.
https://doi.org/10.1134/S0018143916030140

6. Shuvalov V. A., Tokmak N. A., Kuchugurnyi Yu. P., Reznichenko N. P. Braking of a magnetized body at the interaction of its magnetic field with a rarified plasma flow. High Temperature. 2020. V. 58, No. 2. Pp. 151-161.
https://doi.org/10.1134/S0018151X20020182

7. Shuvalov V. A., Gorev N. B., Tokmak N. A., Kuchugurnyi Y. P. Drag on a spacecraft produced by the interaction of its magnetic field with the Earth's ionosphere. Physical modelling. Acta Astronautica. 2020. V. 166. Pp. 41-51.
https://doi.org/10.1016/j.actaastro.2019.10.018

8. Report on the Activities of the National Academy of Sciences of Ukraine in 2020. Kyiv: Akademperiodyka, 2021. 593 pp. (in Ukrainian)

9. Shuvalov V., Lazuchenkov D., Gorev N., Kochubei G. Identification of seismic activity sources on the subsatellite track by ionospheric plasma disturbances detected with the Sich-2 onboard probes. Advances in Space Research. 2018. V. 61. No. 1. Pp. 355-366.
https://doi.org/10.1016/j.asr.2017.08.001

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