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NUMERICAL SIMULATION OF THERMAL CONDITIONS AT THE MOON

Danishevskyy Vladyslav, Dr. Sc. (Tech.), Prof.; **Savytskyi Mykola**, Dr. Sc. (Tech.), Prof.;
Gaidar Anastasia, PhD, Senior Lecturer; **Bordun Maryna**, PhD
State Higher Education Institution
"Prydniprovska State Academy of Civil Engineering and Architecture"

Problem statement. For several decades, long-term inhabited structures for deep space explorations have been of a great interest for the largest space agencies and research communities (see, for example, a recent review by Benoraya [1]). The Moon is the closest celestial body to Earth. Thus, it is considered as the crucial point of the human space infrastructure and as the first place for the development of permanent settlements. Creation of the lunar outpost allows in the near future conducting medical and biological research, testing systems of extraterrestrial human life and performing unique physical experiments.

The lunar environment is characterized by very contrast thermal conditions. At the equatorial latitude, the surface temperature changes from about 100 K to 400 K during the lunar diurnal cycle [2], which lasts approximately 28 Earth days. Simonsen et al. [3] reported the specified range from 120 K to 374 K. Therefore, ensuring the efficient climate control of a lunar habitation module requires a precise simulation of the extreme temperature variations at the Moon.

Purpose of the study. This paper aims to simulate the heat balance at the lunar surface and to evaluate the depth temperature distribution in the lunar soil and its evolution in time.

Main results. The inclination of the lunar equator to the ecliptic plane is very small and equals 1.54°. Therefore, the annual variations of the intensity of solar radiation at the Moon can be neglected.

Almost the entire lunar surface is covered by the regolith layer, which thickness varies from 5 meters in mare areas up to 15 meters in old highland regions [2]. The properties of the regolith were reported by Langseth et al. [4], who revised the results of Apollo missions and estimated the average data valid for all landing sites.

We introduce the governing heat conduction equation that describes a non-stationary heat flow in the regolith layer. The boundary conditions are as follows:

1. The heat flux at the lunar surface equals to the difference between the solar heat gain and the heat loss through the infrared radiation. The solar heat gain is represented as a function of the lunar albedo (which equals approximately 0.09 [5]), the geographical latitude, and on Sun elevation angle. The power of the infrared radiation is determined by the Stefan–Boltzmann law. The lunar surface emits as a nearly black body with the emissivity of about 0.9…0.95 [6].
2. In depth, far away from the surface, the temperature is constant and does not change in time.

The initial temperature of the entire regolith layer is assumed to be equal to the depth temperature. Then, performing numerical simulations during several diurnal cycles, one can observe that the alterations of the regolith temperature stabilize and become completely periodical. This approach allows us to determine the temperature variations at the lunar surface and in the regolith layer, as well as to predict the magnitude of the depth temperature.

The governing initial-boundary value problem is integrated numerically by the finite-difference method using Maple. Temperature at the lunar surface is presented in Figure 1. The obtained results agree with the data from literature [2; 3]. In order to verify the developed model, simulations of the Moon temperature were performed in FEM package ELCUT. Both solutions are in a good agreement.

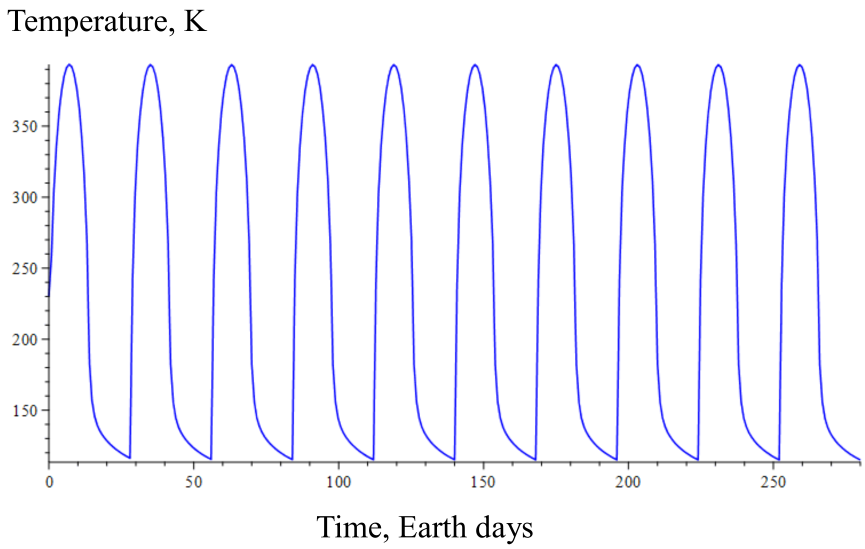

Fig. 1. Lunar surface temperature at the equatorial latitude

Conclusions. A mathematical model describing the Moon thermal conditions is developed. The proposed non-stationary heat problem is solved numerically, which allows one to determine the heat flux at the lunar surface and the temperature distribution in the regolith layer. The results of the analysis are justified by the FEM modelling using ELCUT. The developed model can be further employed for the design of lunar habitation modules.

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