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STUDY OF THERMAL CONDITIONS OF LUNAR HABITATION MODULES

Danishevskyy Vladyslav, Dr. Sc. (Tech.), Prof.; **Savytskyi Mykola**, Dr. Sc. (Tech.), Prof.;
Bezverkhyi Dmytro, B. Sc., Stud.; **Kuchyn Illia**, PhD, B. Sc., Stud.
State Higher Education Institution
"Prydniprovska State Academy of Civil Engineering and Architecture"

Problem statement. The lunar environment is characterized by extreme physical conditions [1], which present high risks for human health. The proper design of a lunar habitation module must secure the crew from various hazards, such as solar flare radiation, galactic cosmic rays, micrometeoroids, and dramatic temperature variations. Protection from radiation and meteoroid impacts can be ensured by a regolith shield placed on the top of the structure. The thickness of the shielding layer is usually considered to be of about 2…2.5 meters [2; 3]. At the same time, providing the efficient climate control of the habitation module requires precise simulations of its thermal conditions as well as predicting the heat flows in the surrounding regolith mass.

Purpose of the study. This paper aims to simulate the heat balance of the lunar habitation module and to evaluate the required power of its heat and/or cooling systems.

Main results. As illustrative design examples, we consider axisymmetric igloo-shaped structures that consist of a stiff foundation plate fabricated from the sintered regolith and an inflatable spherical shell made of high-strength synthetic fibrous materials (e. g., Kevlar or Vectran). It should be emphasized that using inflatable structures in space has a number of practical advantages: high strength (because of the absence of bending moments), low-weight, small packaging volume, etc. [4]. Following the recommendations of Benaroya and Bernold [5], the dimensions of the habitation module intended for the crew of 8 persons are as follows: the height is 4 meters, the habitable area is 275 meters squared and the total area is 450 meters squared. Three different structural designs are studied: overground, semi-underground and underground (Fig. 1). In every concept, the structure is covered with 2 meters of the regolith shielding.

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 [1]. The properties of the regolith were specified by Langseth et al. [6], who revised the results of Apollo missions and estimated the average data valid for all landing sites:

- bulk density 1 700 kg/m^3;
- thermal conductivity 0.011 W/(m·K);
- specific heat capacity 670 J/(kg·K).

The problem of non-stationary heat conduction through the regolith mass surrounding the habitation module is studied. The heat flux at the lunar surface is simulated as the difference between the solar heat gain and the heat loss through the infrared radiation. In depth, far away from the surface, the temperature is constant and does not change in time. The temperature at the inner walls of the habitation module is assumed to equal 18 °C. Numerical simulations are performed in FEM package ELCUT.

Illustrative results for the semi-underground module located at the equatorial latitude are shown in Figure 2 for different times of Lunar day. One can observe that the daily heat waves propagating in the regolith layer are damped at the depth of about 1 meter, while the deeper temperatures are nearly constant and equal 231 K. These results are in a good agreement with the experimental data of the Moon missions [1].

Due to the very low thermal conductivity of the regolith, the heat loss of the habitation module is considerably small and ranges from 145 W for the underground structure up to 255 W for the overground one. It should be noted that the intensity of internal heat sources (i. e., people and equipment) is significantly higher. The latter may be estimated in a range from 1 kW per a crew member (the space project Gemini in 1965–66) up to 10 kW and even more (the International Space Station). Therefore, the lunar habitation module for the crew of 8 persons should be equipped by the cooling system with the power performance of up to 80 kW.

Conclusions. Numerical simulations of the thermal conditions of lunar habitation modules are presented. It is shown that the regolith covering provides a nearly perfect thermal insulation, so the powers of heat sources inside the modules are essentially higher than the heat losses to the external environment. Therefore, the design of efficient colling systems is crucially important for creating a comfortable and safe environment for the lunar crew. Possible engineering solutions may include overground infrared heat radiators. Such devices are expected to have high surface albedo so that to minimize the solar heat gains.

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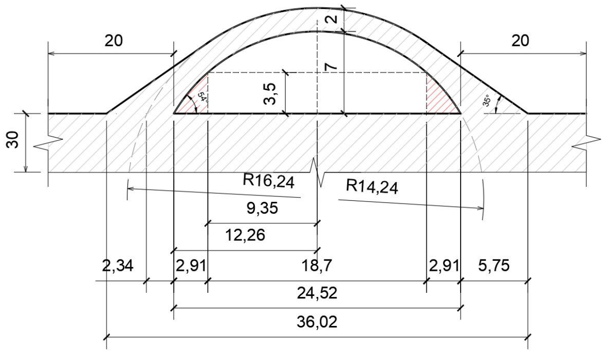
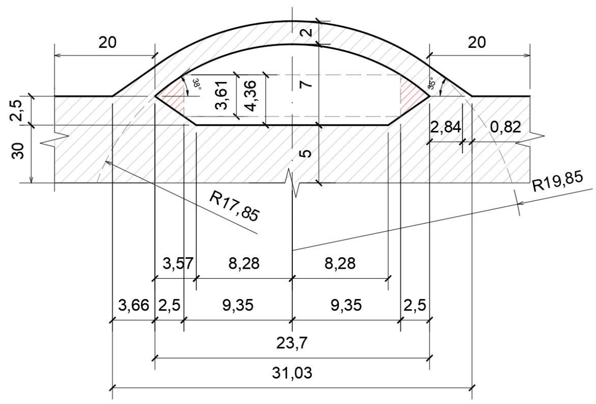
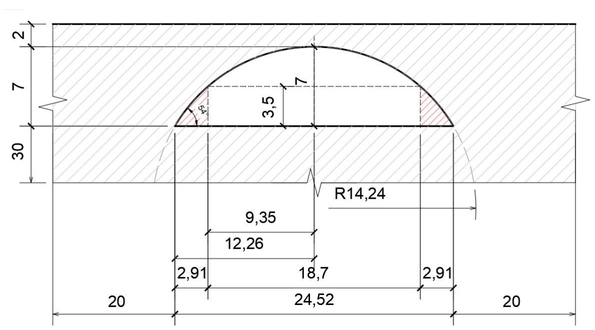


a) overground

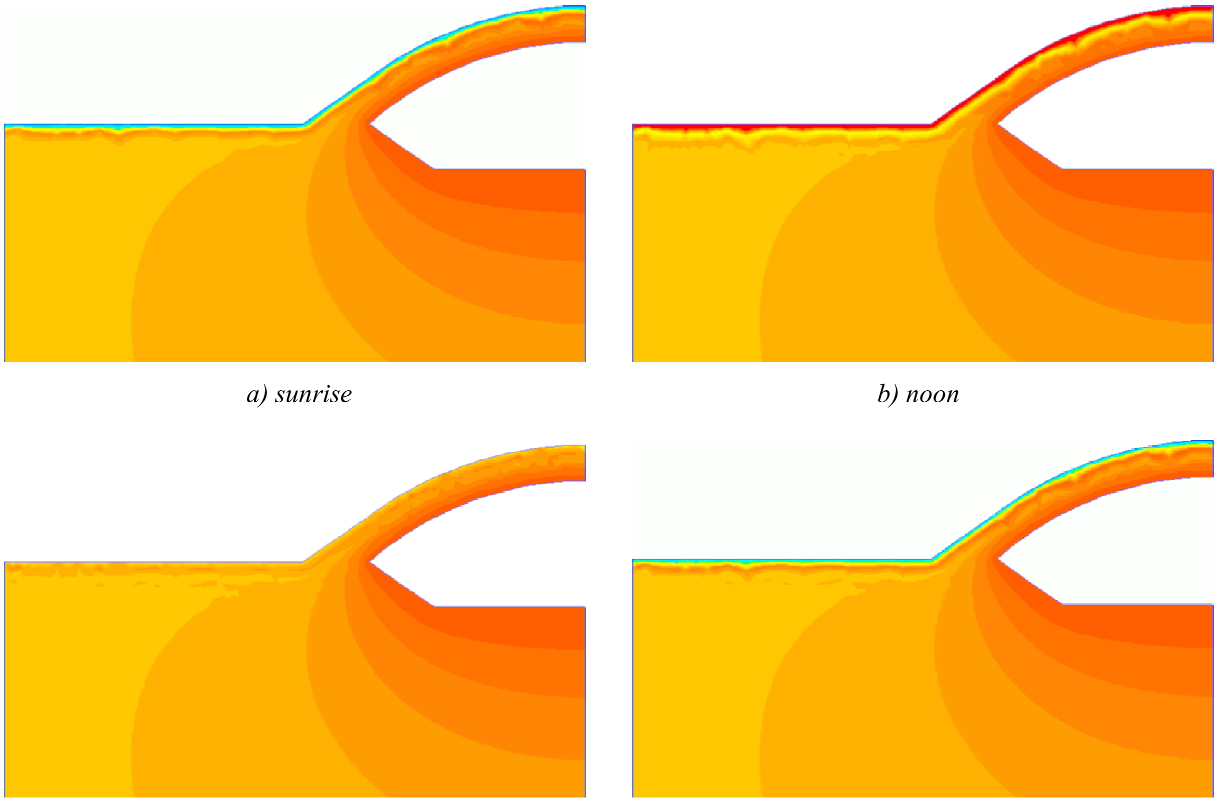


b) semi-underground



c) underground

Fig. 1. Structural design of the lunar habitation modules



a) sunrise *b) noon*

c) sunset *d) midnight*

Fig. 2. Fragments of the temperature field distribution for the semi-underground module.
The colour scale: 110…390 K

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