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SIMULATION OF THE LUNAR DUSTY PLASMA EXOSPHERE INTERACTIONS WITH A LUNAR LANDER

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ABSTRACT

One of the complicating factors of the future robotic and human lunar landing missions is the influence of the dust. The absence of an atmosphere on the Moon's surface is leading to the compaction and sintering of the dust particles found on the Moon surface. Properties of regolith as well as near-surface lunar exosphere depend on many factors, including the solar activity, lunar local time, position of the Moon relative to the Earth's magnetotail. The upper insulating regolith layer is electrically charging by photoelectron emission due to solar UV radiation and solar wind particles. Positive charge is created on the lunar illuminated side, while its night side is negatively charged. Charge distribution, and thus surface potential, depend on the lunar local time, latitude and the electrical properties of the regolith (the presence of water in the upper layer of the regolith, for example, might change the regolith electric conductivity).

Understanding of mechanisms of the dust electric charging, dust levitation and Lander electric charging is essential for interpretation of measurements of two instruments: Dust Impact sensor and Langmuir Probe included in the forthcoming Luna-Glob lander mission what is under development now according to the Russian space program.

One of the tools, which allows to simulate the dust emission from the Moon and asteroids, its transport, deposition and its interaction with a lander, is the SPIS-DUST (Spacecraft Plasma Interaction Software) code [1].

This paper presents first results of SPIS-DUST modelling of the interaction between the lunar exosphere, regolith and a lander. The model takes into account the geometry of the Luna-Glob lander, the electric properties of materials used on the lander surface, as well as Luna-Glob landing place. Initial conditions were chosen based on the current theoretical models of formation of dusty plasma exosphere and levitating charged dust particles.

This paper is the first step in the cooperation between IKI, ESA, ONERA and LATMOS in frame of the Luna-Glob project on simulation of the lunar dusty plasma environment.

1. BACKGROUND

From the first direct observations of dust above the lunar surface made by the Surveyor spacecraft [2] and by the Apollo 17 astronauts [3], dust and dusty plasma near the lunar surface became one of the most mysterious phenomena on the Moon. It was found that surface charging processes drive the transport of lunar dust grains with radii <10 μm, particularly near the terminator [4]. The Surveyor landers observed ~5 μm grains levitating ~10 cm above the surface [2]. During the Apollo missions ~ 0.1 μm-scale dust in the lunar exosphere was observed up to ~100 km altitude [3].The Lunar Dust Experiment (LDEX) onboard the Lunar Dust Atmosphere and Dust Environment (LADEE) observed dust grains around the Moon sustained by the continual bombardment of interplanetary dust particles [5]. It was shown that the dust particles are to exist in heights from 30 to 110 km with velocities of the order of the first escape velocity for the Moon [6]. The most obvious mechanism proposed to explain these observations have been based on the principle that the like-charged surface and dust grains act to repel each other such that dust is lifted away from the surface [7]. Under certain conditions, the heavier grains are predicted to electrostatically levitate near the surface [8], while the smaller grains are electrostatically “lofted” to ~10km in altitude [4]. These phenomena could present a significant hazard to future robotic and human exploration of the Moon [7,9]. The fact that dust can float above the lunar surface helps explain a number of short-term lunar phenomena, such as browning, reddish and bluish glow dawns and the shadow and contrast effects.

In fact, the dust on the surface of the Moon is part of dusty plasma systems. Currently dusty (complex) plasmas researching is widely distributed in the world and covers a numerous works on astrophysics, space plasma physics, the science of planets, atmospheric physics, controlled thermonuclear fusion, the different technological applications and other. Understanding of the processes taking place in a dusty plasma considerably improved since the mid-1990s when the laboratory began to intensively connecting experimental and theoretical study of dusty plasma. This fact significantly motivates the using of methods developed in these studies to the Moon dusty plasmas. Despite a number of works on the study of dusty plasma processes, which involve lunar dust [10], many issues relating to the processes of dusty plasma above the Moon remain open. For example, there is still no definitive understanding of the mechanisms of separation of particles of lunar dust on the surface of the Moon; not developed a comprehensive theory that explains the existence of dust particles at altitudes of the order of several tens of kilometers (up to ~ 100 km) above the Moon; no final clarity regarding the electrical properties of the lunar regolith (the quantum yield and the work function), important in the description of dusty plasma system over the moon [11]; not taken into account the effects of secondary electron emission, electron-ion emission, etc. on the processes of charging of dust particles which, as shown by some estimates [12], it is important, at least in the area of the lunar terminator; not described dusty plasma system in a situation where the Moon is in Earth's magnetotail; etc.

Therefore it is very important to investigate this phenomena during the new missions. Two lunar landers are scheduled for launch since 2019 according to the Russian space program. The both landers will carry a Dust Instrument PmL, Brief introduction of this instrument is in chapter 2.

Before the launch, it is necessary to study possible influence on Dust Instruments and its measurements from dust particles and dusty plasma. There are a number of Software products that can simulate influence between spacecraft and surrounding plasma. Chapter 3 deals with the options and advantages of various software.

In Chapter 4 we demonstrate the current results of the simulating SC-Dusty plasma interactions with SPIS-DUST software. Also we make some conclusions due to that results.

2. THE DUST INSTRUMENT ONBOARD THE LUNAR-GLOB LANDER

The "Luna-Glob" lander on the surface of the Moon is under development in Russia. The payload of this spacecraft includes an instrument PmL for study of dust particles dynamics over the lunar surface and sensors for estimation of the electric field under the surface. PmL device comprises three units: the Impact Sensor (IS) and 2 electrostatic probes (EP).

IS is designed for registration of dust particles levitating above the surface of the Moon, as well as micrometeorites and secondary particles ejected from the lunar surface. IS has two types of sensors: piezoelectric sensors for registering the momentum of the dust particles and charge-sensitive grid for the measurements charges of particles that pass through the grid. In addition, a time of passage through the grid and the time of collision of the particle with a piezoelectric sensor will provide the speed of the particle and it becomes possible to estimate the mass of the particle. Structurally, the IS unit contains the secondary power supply board, digital processing board and amplification board. The top of the IS unit is coated with 24ceramics PZT piezoelectric sensors. Charge-sensitive grid located above the PZT sensors.. The IS block shown on Fig. 1.

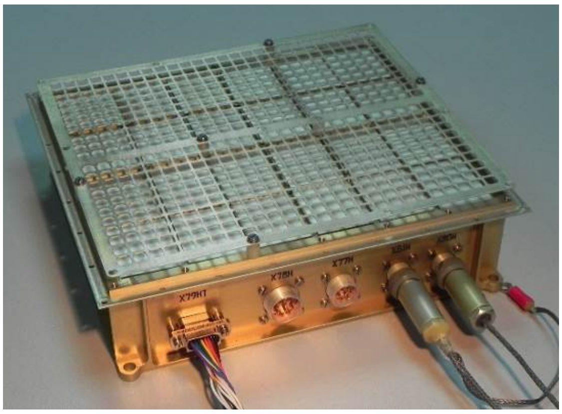

Figure 1. Impact Sensor

Each of the EP unit contains two Langmuir probes to measure plasma parameters and to estimate the vertical component of the electric field and charge sensitive sensors. The EP unit shown in Fig. 2.

Figure 2. Electrostatic Probe

Each of the EP unit contains two sensors: a Langmuir probe to measure plasma parameters and to estimate the vertical component of the electric field and charge sensitive sensor. The EP units contain no active

electronics. The EP electronics included in the IS unit contains a power supply(the reference voltage range between -88 V to +88 V for the Langmuir probe)and the processing the analog signal.
IS is located at about 0,7 mm above the lunar surface and its aperture is to be directed on the lunar west. Both of the EP units are mounted on the lander (and one of them is very near with solar array) on the different heights: 0,7 m and 1,4 m above the surface, the both directed to the west. The allocation of each sensor is shown on Fig. 3.
Two EP sensors are mounted on the lander at the altitude 0,7 m and 1,4 m from the surface .

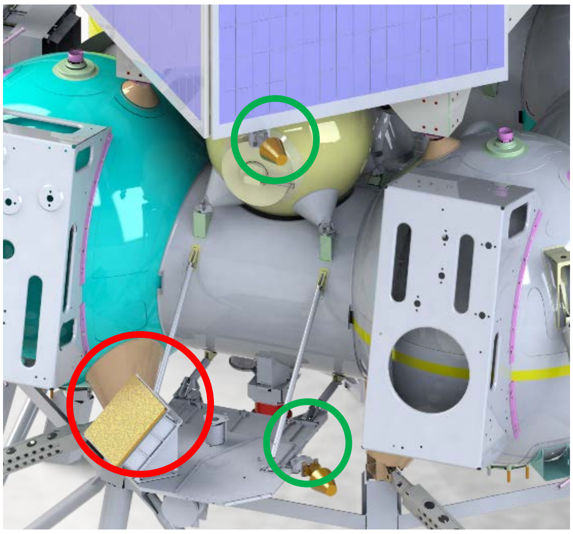

Figure 3. Allocation of the PmL units. ES marked with green circles and IS marked with red circle.

As we can see, the problem with allocation occurs. With this configuration, we have to estimate the influence of the spacecraft on the lunar exosphere plasma due to the disturbances of plasma and fields near the Langmuir Probes. Either we have to calculate the possible dust fluxes with the different conditions depending on the local time on the Moon and the relative position to Earth and Sun.

3. SOFTWARE COMPARSION

We believe that the lander on the lunar surface has to disturb the ambient plasma and skew measurements of et least the Langmuir probe.To estimate the lander-plasma interaction weuse simulation code.
Some special spacecraft charging software are known: NASCAP-2K, SPIS (SPIS-DUST modification), Coulomb-2 and MUSCAT.
According to [13], the results of on-orbit simulation in these software in the case of potentials are similar and in the plasma distribution are mostly similar.
However, the dust modification of SPIS (SPIS-DUST) takes into account lunar dust fluxes and properties of lunar surface, and this modification had been developed exactly for the simulation of physics of the dust charging and transport above the lunar surface [1].

4. PRELIMINARY RESULTS OF THE SIMULATION

For the first simulations we used a simple model of the Luna-Glob lander with legs, solar arrays, placed on the surface inside the simulation box with dimensions 10x10x60 m (Fig. 4).

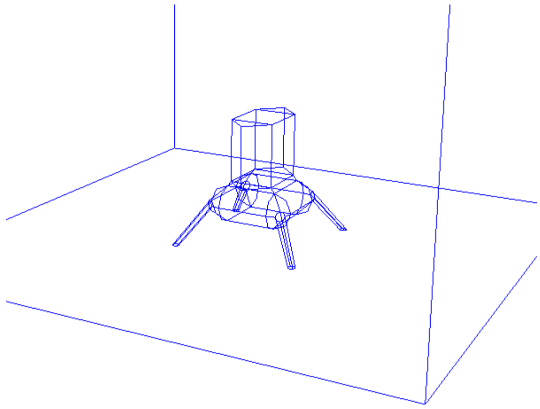

Figure 4. Luna-Glob simulation model

The duration of the simulation was 1 s. In this simulation we did not took into account the relative position of the lander to the Sun, Earth's magnetotail and other parameters from the proposed landing site. We assumed in this simulations that the Sun at its zenith.
Using these conditions we obtained plasma potential distributions presented at Fig. 5. It is obvious that we will see some deviations from the real plasma potentials, but probably we can estimate that deviations..

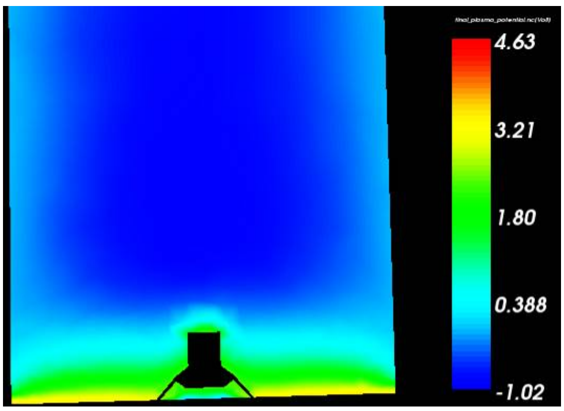

Figure 5. Plasma potentials near the lunar lander after 1 s of simulation calculated with SPIS-DUST software

Results of the simulations of the dust number density near the lander presented at the Fig. 6. We can see that in this conditions there is a significant amount of dust particles near the spacecraft.

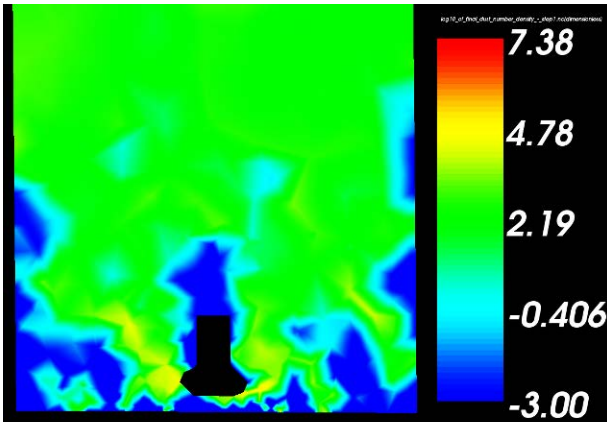

Figure 6. Log 10 of final dust number density around the SC after 1 s of simulation

5. CONCLUSION

The SPIS-DUST code seems to be a powerful tool for the simulation of the Lander electric charging and the Lander plasma-dust environment and can be very useful for our purposes. The results of this code can be used for the deeper understanding and interpretation of the dust and plasma measurements made onboard the Lunar Lander. This code is planned to be used for the detailed simulations of the future Russian Luna-Glob and Luna-Resource Landers.

6. ACKNOWLEDGEMENTS

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