A Review Article on Effect of Surface Topography on Dust Levitation in Lunar Environment

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***Abstract*— This paper explains the basic concept of a lunar surface topography and charging phenomenon. Moon is natural satellite of the earth as well as closet object to it. Moon was formed about 4.6 billion years ago. It is continuously exposed to solar rays and solar wind plasma. Due to large craters and elevation angle of the sun, some part of the surface is exposed to sunlight while other may be in shadowed region. This may charge lunar surface with few value of potential. Here we studied few papers related to same problem which gives the idea about lunar surface charging, levitation and effect of surface topography.**

Index Terms— crater; levitation; lunar; plasma; solar wind; topography

I. INTRODUCTION

Surface of the moon is continuously exposed to solar UV rays during the day; at same time, the night side of the moon is exposed to solar wind electrons [1]. This causes charging of the lunar surface. The dust layer on the lunar surface, formed by volcanic eruptions, meteorite impacts, solar radiation, and solar wind plasma etc. [2]. Electrostatically charged dust may loft tens to hundreds of kilometers above lunar surface [3]. Effect of solar rays and wind plasma is shown in Fig. 1. Earth is protected by solar UV rays but moon has no global magnetic field. Dust on the moon; interact with solar rays and plasma wind that causes charging of them. Thus, dust grains are electrified due to effected by solar wind [4] as shown in fig. 1.

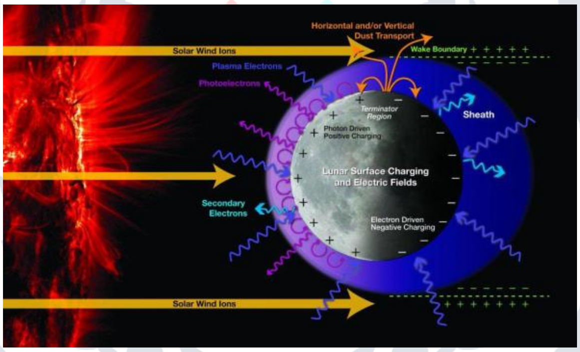

Fig 1: Effect of solar rays on lunar surface [4]

Here, the part of lunar surface is exposed to solar rays and illuminated while other region is shadowed region. On the day side, electrons will knocked out from the lunar surface and it becomes positively charged. Electrons are lighter in weight so they travel faster and reach to the surface earlier. So, the positively charged layer will first neutralized by the electrons. When more electrons will captured by the surface, the layer will become negatively charged. Charging phenomenon depends on UV rays, plasma conditions as well as the speed of the electrons [2]. So, there will be a region where there will be no charging of the dust and dust on that region may not loft. That region is called terminator or dead zone [5].

II. LEVITATION OF LUNAR DUST [3]

Lunar surface is dielectric and when any ion or electron impinges the surface; its charge is deposited on the surface at that location. Dust on the lunar surface may charge and levitation condition of dust grains can be given by below equation [3],

$$Q_d E_s \geq F_g + F_c. \tag{1}$$

Where Q_d is charge of dust grain, E_s is electric field, F_g is gravitational force and F_c is adhesive force between dust grain and surface. Here, when force on the dust grain exceeds the gravitational force, dust on the moon levitated above the surface. Electrostatic levitation and charging are closely related with each other. Electrostatic charging, electric field on the surface and plasma sheath near lunar surface largely determine whether dust on surface will levitated and how far above it will arise. This height is called the Debye length [3]. Lofting of the dust grains also depends on the size of the particle. Maximum radius up to which the particle lofted is be given by below equation [5],

$$r_{max=} (3\varepsilon_0/\rho g_L \lambda_d)^{1/2} .|\phi_s| \tag{2}$$

Where, r_{max} is radius upto which dust may be lofted, ε_0 is free space permittivity, ρ is dust grain density, g_L is acceleration due to lunar gravity, λ_d is is Debye length shielding and ϕ_s is surface potential of lunar surface. On day side, $\phi_s > 0$ and at night side $\phi_s < 0$ as explained in section I.

III. LITERATURE SURVEY

The following papers are useful for the study of surface topography and levitation of dust.

(a) Lunar Dust Transport [2]:

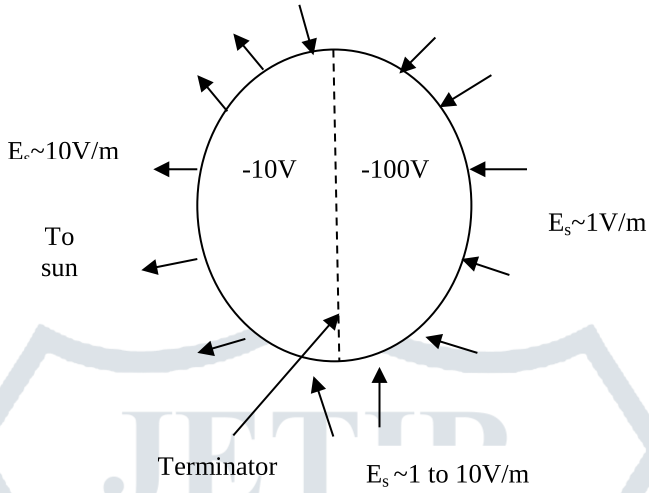

Fig 2: Charging of the lunar surface[6]

Moon has formed almost 4.6 billion years ago and surface of moon is covered with fine dust. Basically, moon has no atmosphere. Yet, Apollo and surveyor mission had observed an atmospheric glow in horizon and streamers of dust arising from the surface. Dust scattered due to solar radiation. The Apollo landing sites observed that moon is an ocean of charged dust particles with adhesive property. The returned soil sample from the moon showed that 20 percent of the soil is covered with particles with size below 70µm [2]. Size of lunar dust varies from nanometer to 20µm. Moreover, because of the photoemission effect causes the particles may be charged positively on the day side region while negatively on the night side. There is a region between illuminated (sunlit) and shadowed (dark) region which is called terminator.

Charging of lunar surface is due to constantly bombarding of cosmic dust which acquires high electrostatic charge by the photoemission of electrons. So, electric potential will developed on the surface. Apart from this, solar wind charging process is also complicated when the moon passes through the earth's magnetotail for a period about six days each month during full moon. During this time the surface of the moon is charged due to earth's magneto spheric plasma sheath. Dust particles will charge more due to involvement of high energy of electrons. Here, maximum charging of lunar dust depends on the solar wind or earth's magnetotail. It also depends upon equilibrium potential or electrostatic field reached by negative charging [2]. The direction of electrostatic field is opposite to positively charged dust grains. Equation for electric field generated over lunar surface is given by below equation [2],

$$E = \sigma / \epsilon_0 \tag{3}$$

Where, E is electric field generated by dust layer, σ is surface charge density and ϵ_0 is permittivity of free space.

This model predicts that a very small (<<0.01 µm) positively charged grains above the day-side, a region in the Dead Zone where no detection occurs, and larger (0.01-0.1 µm) negatively charged grains around the terminator region [5].

(b) The Effect of Surface Topography [7]:

Table 1: Change in electric potential as a function of height

Height from lunar surface[m]	**Approximate potential (V)**
1-2	3-4
2-5	1.5-3
6-10	0.5-1.4
Above 10m	~0

IV.

Lunar surface is continuously exposed to solar UV light during the day time. Solar rays contain electrons and ions. Zenith angle can be defined as, the angle measured directly overhead to geometric center of sun's disc using horizontal co-ordinate system

[8]. On the day side for a small solar zenith angle (SZA), value of photoemission current is larger than ambient plasma collection current so the photo electron sheath develops near and above the lunar surface. As the SZA increases, it is expected that plasma sheath becomes weaker and at night time turns in to negative layer [7].

Lunar surface is not plain region and topography of the surface is uneven. Due to presence of craters and boulders on the surface, “mini-wakes” are generated due to complex electric field developed on the surface [7]. Complex electric field near craters and boulders creates the electrostatic transport of lunar dust and dust grains will accumulate on the surface via electrostatic transport over long period of time.

Crater of the 7m of diameter from range -3.5 to +3.5 is taken by author. Crater is along with the equatorial plane so results were presented at sub solar point with 0º SZA. Height of the crater is lower than the surrounding flat surface so the photoelectron sheath is weaker. Crater has the slopping floor so photoemission will decrease inside it and therefore charges less. Crater traps larger grains at higher efficiency than smaller grains due to varying electrostatic and gravitational force as a function of grain size. Change in potential with height is shown in table 1.

When the dust grain is charged, it launched off the surface. The force on the dust grain is calculated by Lorentz force equation. Magnetic field can be ignored as moon has no magnetic field.

(c) The Lunar Dust Pendulum [9]:

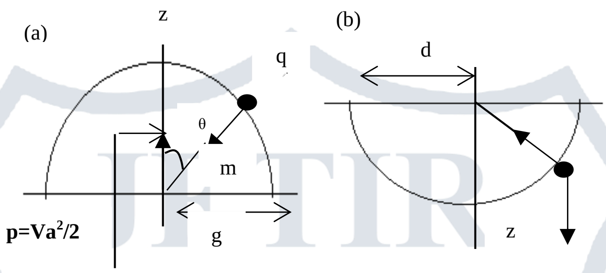

Fig. 4: Electrostatic pendulum and gravitational pendulum [8]

Because of the moon has very less amount of atmosphere so charged particles and photons are absorbed by the surface [9]. Due to this potential is generated on the surface and it comes positively or negatively charged. Apart from this, shadowed crater has negative potential compared to surrounding lunar surface in sunlight. Lofting of dust occurs up to several tens to hundreds of kilometers and follows the ballistic trajectory. Lunar electric field particularly near terminator and at uneven topography will not be confined to vertical direction and have significant horizontal component also.

There exist a relation between the standard gravitational pendulum and lunar dust pendulum which is shown in fig. 4. Fig.4(a) describes electrostatic pendulum or lunar dust pendulum while fig.4(b) describes gravitational pendulum. Here, in both cases the length of the pendulum is d. For lunar dust pendulum it is distance from the crater center and for gravitational pendulum it is length of string. For both cases z describes the vertical distance and potential energy increases with z. Time period for gravitational pendulum is given by below equation [9],

$$T = 2\pi\,(d/g)^{1/2} \tag{5}$$

While time period for lunar dust pendulum is given by below equation [9],

$$T = 2\pi d\,(2md^2/qV_0)^{1/2} / a \tag{6}$$

Here m represents the mass on the string for fig (b); T represents period of isochronous, q represents charge of dust grain. From above two equations we can conclude that there exists scaling relationship in the models. If we reduce the charge of dust grain by four, period will increase by two.

Due to effect of Debye length shielding radius decreases. Because the equilibrium trajectory is unstable, Debye shielding will affect the dust grains and dust grains may be deposited in to the crater [9]. The results presented here with the prediction of horizontal and vertical motion of dust grains. Because the model predicts oscillatory motion across the crater, it also shows that dust may be transported horizontally but not with a great distance. In general, though, there is large number of dust grains presented on the lunar surface, only a small fraction of the dust needs participate in the levitation process.

Similarly, dust levitation height changes drastically around a region called terminator. Here surface electric field E_s~0. This drastic change occurs due to surface electric field and the electric field profile. Hence, if dust levitation occur and charge of the dust reaches up to $Q_{d,min}$ there will be drastic increase in the dust levitation height from the terminator region to transition point [3]. At night, the surface is negatively charged. So the dust grain will maximum levitated due to negatively charged at night time. Dust levitation in the terminator region is influenced by ambient plasma and surface charging condition and varies significantly even for the small changes in solar elevation angle[3]. All this conclusions are derived from the modeling of dust particles [3].

In dynamic dust fountain model, once the dust has attained sufficient charge and to overcome lunar gravity and cohesive force, it will leave the surface. Equation can be given by below equation [3],

$$F_q > F_g + F_c \tag{7}$$

Here, F_q is electrostatic force, F_g is gravitational force and F_c is cohesive forces. The dust grain that leaves the sheath region with an upward velocity follows a near parabolic trajectory toward the lunar surface as the main force acting on it is gravity [5].

Moreover, surface charging is driven by photoelectrons on the dayside and plasma electron during the night time which affects the grain lofting height.

IV. SUMMARY AND FUTURE WORK PLAN

From the above references we have presented an overview of the charging phenomenon and levitation of the dust grain. It conveys that topography of the surface highly affects the charging of the lunar dust. Since moon has thin atmosphere dust grain may lofted above from the lunar surface up to several tens to hundreds of kilometer. Size of craters and boulders also affect the charging of the dust grain.

Here, our work is to take few arbitrary shapes of craters which affect the landing. Particle-in-cell method can be used to provide information about several parameters like potential, density, electric field etc. The work is to investigate the role of craters in lunar landing site, note the changes that occur in these parameters for various cases and simulate it via MATLAB.

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