1 Lunar Dust Damage Prevention

A. Gravity & Motion in Lunar Conditions

Lunar gravity affects dust movement and impact forces. Acceleration due to lunar gravity:

$$g_{\text{Moon}} = 1.625\,\text{m/s}^2$$

Projectile motion equations (dust particle trajectories): - Horizontal displacement:

$$x = v_0 \cos(\theta) t$$

- Vertical displacement:

$$y = v_0 \sin(\theta) t - \frac{1}{2} g_{\text{Moon}} t^2$$

- Time of flight:

$$t_{\text{flight}} = \frac{2 v_0 \sin(\theta)}{g_{\text{Moon}}}$$

- Impact velocity:

$$v_{\text{impact}} = \sqrt{v_x^2 + v_y^2}$$

B. Dust Adhesion (Electrostatic Forces)

Coulomb's Law (force between charged dust and material surface):

$$F = k_e \frac{|q_1 q_2|}{r^2}$$

where: $k_e = 8.99 \times 10^9\,\text{Nm}^2/\text{C}^2$ (Coulomb's constant) q_1, q_2 = charge of dust particle and surface r = separation distance

Electric field near a charged surface (simplified as a plate):

$$E = \frac{\sigma}{\varepsilon_0}$$

where: σ = charge density on the surface $\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F/m}$ (permittivity of free space)

C. Dust Impact & Erosion (Abrasion Damage)

Kinetic Energy of Dust Impact:

$$KE = \frac{1}{2} m v^2$$

where: m = dust particle mass v = impact velocity

Stress from impact (for wear and material erosion):

$$\sigma = \frac{F}{A}$$

where: A = impact area

Hertzian Contact Stress (if particles are spherical and deform material):

$$P_{\max} = \frac{3F}{2\pi a^2}$$

where: a = contact radius

2 Thermal Insulation

A. Heat Transfer Mechanisms

Since space is a vacuum, conduction is minimal, and heat transfer is dominated by radiation.

Thermal Conductivity (Fourier's Law - for conductive heat transfer, if necessary within materials):

$$Q = -kA\frac{dT}{dx}$$

where: k = thermal conductivity of material A = surface area $\frac{dT}{dx}$ = temperature gradient across the material

Thermal Radiation (Stefan-Boltzmann Law):

$$P = \sigma\varepsilon AT^4$$

where: P = power radiated $\sigma = 5.67 \times 10^{-8}\,\mathrm{W/m^2K^4}$ (Stefan-Boltzmann constant) ε = emissivity of the material A = surface area T = absolute temperature in Kelvin

Radiative Heat Exchange Between Two Surfaces:

$$Q = \sigma A\varepsilon\left(T_1^4 - T_2^4\right)$$

where: T_1, T_2 = temperatures of the two surfaces

3 Cosmic & Solar Radiation Protection

A. Particle Radiation Interactions

Energy of a Cosmic Ray Particle (Relativistic Energy Equation):

$$E = \gamma mc^2$$

where: $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ (Lorentz factor) m = particle rest mass c = speed of light

Linear Energy Transfer (LET) - Energy deposited per unit distance:

$$LET = \frac{dE}{dx}$$

where: dE = energy lost dx = distance traveled

Stopping Power (Bethe-Bloch Equation for Charged Particles in Matter):

$$-\frac{dE}{dx} = \frac{4\pi N_A r_e^2 m_e c^2 Z}{\beta^2 A}\left[\ln\left(\frac{2m_e c^2\beta^2\gamma^2}{I}\right) - \beta^2\right]$$

where: N_A = Avogadro's number r_e = classical electron radius m_e = electron mass Z, A = atomic number and mass number of shielding material $\beta = \frac{v}{c}$ γ = relativistic factors I = mean excitation energy of the material

B. Shielding Effectiveness

Attenuation of Radiation in a Material (Exponential Absorption Law - Beer-Lambert Law for X-rays and gamma rays):

$$I = I_0 e^{-\mu x}$$

where: I_0 = initial intensity of radiation I = intensity after passing through the material μ = linear attenuation coefficient (material dependent) x = thickness of shielding

Radiation Dose (Energy Absorbed by Material, Gray Units - Gy):

$$D = \frac{E}{m}$$

where: D = dose in Gray (J/kg) E = total energy absorbed m = mass of material

Equivalent Dose (to Account for Different Radiation Types - Sieverts, Sv):

$$H = D \times Q$$

where: H = equivalent dose in Sieverts (Sv) Q = radiation weighting factor (depends on type: 1 for X-rays, 20 for alpha particles)