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Particle drag along the surface

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ABSTRACT

I will discuss the drag of particles on granular surfaces by a fluid. I will present simulations using FLUENT of Aeolian saltation under Earth and Mars conditions obtaining among others the static and dynamic threshold shear and the height of the saltation layer as function of the wind strength. A universal quadratic increase of the saturated flux as function of the difference from the threshold is established.

The motion of sand grains in a sequence of ballistic trajectories close to the ground is called saltation and is a major factor for surface erosion, dune formation and triggering of dust storms on Mars. Although this mode of sand transport has been matter of research for decades both through simulations and wind tunnel experiments under Earth and Mars conditions, it has not been possible to provide accurate measurements of particle trajectories in fully developed turbulent flow. Here we calculate the motion of saltating grains by directly solving the turbulent wind field and its interaction with the particles. On the basis of our results, we arrive at general expressions which can be applied to calculate the length and height of saltation trajectories and the flux of grains in saltation under different physical conditions, when the wind velocity is close to the minimal threshold for saltation. Our calculations show that the minimal wind velocity required to sustain saltation on Mars may be surprisingly lower than the aerodynamic minimal threshold measurable in wind tunnels. Indeed, Mars grains saltate in 100 times higher and longer trajectories and reach 5–10 times higher velocities than Earth grains do.

We simulate saltation by solving, first, the turbulent wind field inside a long two-dimensional channel (wind tunnel) and, next, the air feedback with the dragged particles. The details of the calculation procedure are described elsewhere [1]. The fluid (air) is incompressible and Newtonian, the Reynolds-averaged Navier-Stokes equations with the standard $\kappa - \epsilon$ model being employed to describe turbulence.

Once steady-state turbulent flow is produced, particles are injected from the inlet at the ejection angle of grain-bed collisions with a velocity of the order of 60 cm/s. Grain trajectories are obtained by integrating the equation of motion:

$$\frac{d\boldsymbol{v}_{\mathrm{p}}}{dt} = F_D(\boldsymbol{u} - \boldsymbol{v}_{\mathrm{p}}) + \boldsymbol{g}(\rho_{\mathrm{p}} - \rho_{\mathrm{fluid}})/\rho_{\mathrm{p}}, \tag{1}$$

where v_{p} is the particle velocity, ρ_{fluid} and ρ_{p} the density of the fluid and of the particles, respectively, and $F_D(\boldsymbol{u} - \boldsymbol{v}_{\mathrm{p}})$ represents the drag force per unit particle mass, where

$$F_D = \frac{18\eta}{\rho_{\mathrm{p}} d^2} \frac{C_D \mathrm{Re}}{24}, \tag{2}$$

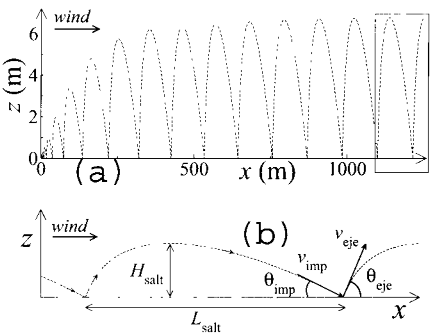

Figure 1: (a) The dashed line represents the trajectory of one saltating grain calculated using parameters for Mars with a wind strength of $u_* = 1.78$ m/s. (b) Typical saltation trajectory obtained in the calculations — the dashed line corresponds to the saltation path enclosed by the box in (a)

$\mathrm{Re} = \rho_{\mathrm{fluid}} d |\boldsymbol{u} - \boldsymbol{v}_{\mathrm{p}}| / \eta$ is the particle Reynolds number, d is the grain diameter, η the air viscosity and the drag coefficient C_D is taken from empirical relations [2]. The feedback on the local velocity of the fluid due to its momentum exchange with the particles is accounted for by adding the momentum change of every particle as it passes through a control volume [1],

The corresponding calculations for Earth are shown in the inset.

As compared to Earth trajectories, Martian saltation paths are giant. While Earth saltating particles do not exceed heights of 15 cm, maximum heights reached by particles saltating under typical sand-moving winds on Mars (fig. 1) amount to $1 - 5$ m. Moreover, Martian grains saltate in $20 - 120$ m long paths — such particles appear rather suspended when seen in a wind tunnel with length of a few meters. The simulation results are in agreement with the expectation that the saltation length L_{salt}.

The present work reports the first calculation of particle trajectories in a turbulent wind. The sand flux, saltation height and length on Mars and on Earth were studied and general expressions were found which can be applied in order to calculate these quantities under different physical conditions, e.g. on the surface of Venus or Titan. The giant saltation trajectories and the high grain velocities on Mars are the missing link to understand the triggering of dust storms under typical wind velocities $u_* \approx 1.0$ m/s at present conditions of Mars.

References

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[2] Morsi SA, Alexander AJ (1972) An investigation of particle trajectories in two-phase flow systems. *J. Fluid Mech.* 55:193–208.