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Drag reduction in the side-by-side motion of intruders in a granular medium

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When solid objects (intruders) move within a fluid, cooperative effects can be observed. We find them, for example, in the motion of a school of fish or when migratory birds fly in a symmetrical V-shaped flight formation. In a more fundamental approach, when two identical spheres move side-by-side at constant velocity in a viscous flow, the drag force is predicted to reduce as the separation between them decreases[1]. Cooperation is also present when intruders move within granular materials[2], and interesting phenomena can be observed. For instance, if the intruders are close from one another, they repel each other; however, at intermediate separations (few diameters apart), they experience attractive forces[3]. In this work, we investigate experimentally how the drag forces acting on a pair of spherical intruders moving amid grains at constant velocity (quasi-static regime) vary with the transverse separation between them Δ and their depth h, as indicated in the scheme of the experimental setup displayed in Fig. 1(a).

Among our findings, we show that, at large separations ($\Delta \gtrsim 3$ intruder's diameter), the two intruders do not interact with each other, and the mean drag force F (determined as the average of the mean drag forces experienced by each of the intruders) remains approximately constant, with its value corresponding to that measured for a single intruder moving under similar conditions. As the separation between intruders is reduced [see Fig. 1(b) for an actual scenario], the mean drag force decreases, with a decrease that can reach around 25%. Furthermore, the amount of relative drag reduction was observed to increase with the intruders depth h, following an approximately linear growth (at least within the studied range of $14 \leq h \leq 49$ mm). Finally, we propose a model for the drag reduction based on the breakup of contact chains caused by the perturbations generated by the neighbour intruder.

Overall, our results bring new insights into the long-range effects when solid objects move together in a granular material, such as happens in the displacement of animals in the soil[4] or the growth of roots[5].

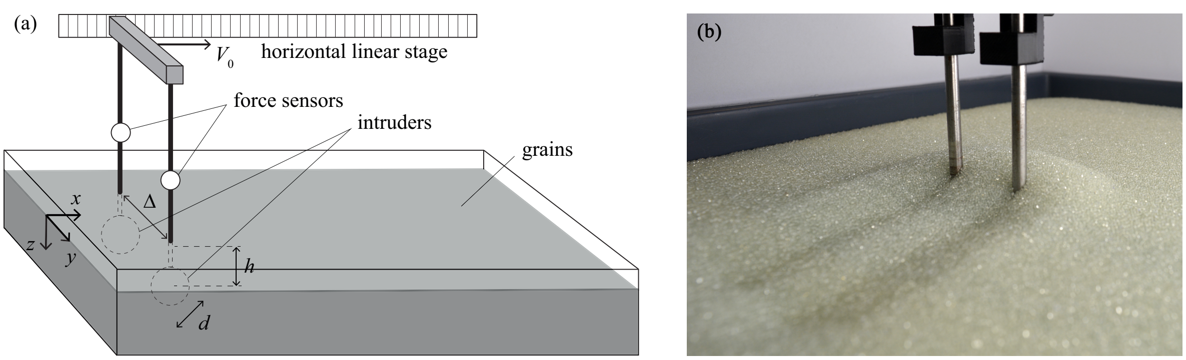

Figure 1: (a) Sketch of the experimental setup for the displacement along the x-axis of two spherical intruders of diameter d, immersed in grains at the depth h. (b) Picture of an experiment for two immersed intruders $\Delta = 30$ mm apart, with diameter $d = 20$ mm, at depth $h = 14$ mm and moving at a velocity $V_0 = 2.7$ mm s^{-1}.

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