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PARTICLE DISPLACEMENTS OVER INTERACTING BARCHANS

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Abstract. *Barchans are dunes of crescentic shape formed in areas of unidirectional fluid flow and limited amount of grains. They can be found in several environments, such as deserts, rivers, oceans, and even on the surface of Mars. Due to the large timescales of desert (years) and Martian (decades) dunes, physicists and geophysicists perform experiments with subaqueous barchans to understand the dynamics of barchan fields in a few minutes. In some recent works, we investigated the short-range interactions of two subaqueous barchans, and showed five different patterns arising from the interaction. It has been proposed that the appearance of different patterns depends on the Shields number and the ratio of the number of particles in each dune. Also, we investigated the binary field of barchans composed of grains of different sizes and proposed a timescale for the collision of the dunes. The present study aims to understand and quantify the displacements of particles over barchans, for both monodisperse and bidisperse mixtures of grains, during different barchan-barchan interactions. The experimental setup consisted of a 5-m-long closed-conduit channel with a rectangular cross-section (width = 160 mm and height = 50 mm). A water reservoir, two centrifugal pumps, a flow straightener, a settling tank, and a return line are part of the equipment as well. With the channel filled with water, two separated quantities of grains were poured in the test section before imposing a water flow, forming two conical piles that were deformed into barchan dunes. A conventional camera, placed on the top of the channel, was used to acquire images of the interactions. Matlab codes were developed to identify and follow particles over time. As preliminary results, we computed mean velocities, mean displacements, and the stopping/moving ratio of particles. Also, for monodisperse dunes, we calculated the movement density and sediment flux. The results of this study may explain why downstream dunes accelerate in some cases, and reveal details of the granular dynamics under different conditions.*

Keywords: *dunes, barchan-barchan interactions, particle displacements*

1. INTRODUCTION

The crescent-shaped dunes, called barchans, are formed in areas of unidirectional fluid flow and limited amount of granular material (Bagnold (1941), Andreotti et al., (2002)). They can be found in several environments, such as deserts, rivers, the bottom of oceans, and even on the surface of Mars. Barchans belong to dune fields, where collision and interaction of dunes of different sizes and speeds may regulate the field dynamics (Hersen et al., (2004)).

For a better understanding of the physics of barchans, scientists have performed experiments with subaqueous dunes because of the smaller length and timescale associated with them (Assis and Franklin (2020), Assis and Franklin (2021), Assis et al., (2022), Endo et al., (2004), Alvarez and Franklin (2017), Alvarez and Franklin (2019), Bacik et al., (2020)) when compared with aeolian dunes (Vermeesch (2011), Bo and Zheng (2013)). Although experiments with subaqueous dunes facilitate the understanding of a barchan field, there are still questions to be answered.

Recently, Assis and Franklin (2020) investigated the short-range interactions occurring between two subaqueous barchans. Varying the grain types (diameter, density, and roundness), pile masses, transverse distances, water flow rates, and initial conditions, five different patterns were identified for both aligned and off-centered configurations, and interaction maps that depend basically on the ratio between the number of grains of each dune, Shields number, and alignment of barchans were proposed.

Previous investigations concerning dune fields were conducted using a monodisperse dune (e.g., only one type of particle). Alvarez et al., (2021) investigated the growth of a barchan dune composed of bidisperse particles, and they

found that denser, smaller, and smaller and denser particles tend to accumulate over the dunes and proposed that the segregation is characterized between fluid entrainment and ease of rolling. Assis et al., (2022) showed that interaction patterns vary with concentrations of particles within each dune, different patterns arising from each barchan consisting of different particles, and they proposed a timescale for the collision for both monodisperse and bidisperse dunes.

Some studies were carried out trying to understand the motion of particles that compose the dunes (Wenzel and Franklin (2019), Alvarez and Franklin (2019), Assis and Franklin (2021)). Penteado and Franklin (2016) showed the displacement and velocity field of grains moving over a flatbed. Wenzel and Franklin (2019) followed particles over a subaqueous barchan dune. The authors determined the velocity field over a single dune and showed that higher particle speeds were near the centroid of the dune. Alvarez and Franklin (2019) followed particles that migrate to horns. It has been shown that these particles exhibit significant transverse displacements. Recently, Assis and Franklin (2021) showed the dynamics of grains exchanged between barchans during the interaction, computed the velocities and displacements of these grains, and proposed a diffusive length for the spreading of grains in the transverse direction. However, physical information on particles over dunes during interactions is still missing.

The aim of this study is to understand the displacement of particles over barchans, for both monodisperse and bidisperse mixtures of grains, during different interaction patterns.

2. EXPERIMENTS

The experimental setup consisted in a 5 m long closed-conduit channel with a rectangular cross section. A water reservoir, two centrifugal pumps, a flow straightener, settling tank and return line are part of the equipment as well. A divergent-convergent nozzle with glass spheres of 3 mm in diameter was used, and its function is to homogenize the flow inside the channel. The test section is 1 m long and starts 40 hydraulic diameters downstream of the channel inlet. With the channel filled with water, two separated quantities of grains were poured in the test section before the channel started to run. Figure 1 presents the layout of the experimental setup.

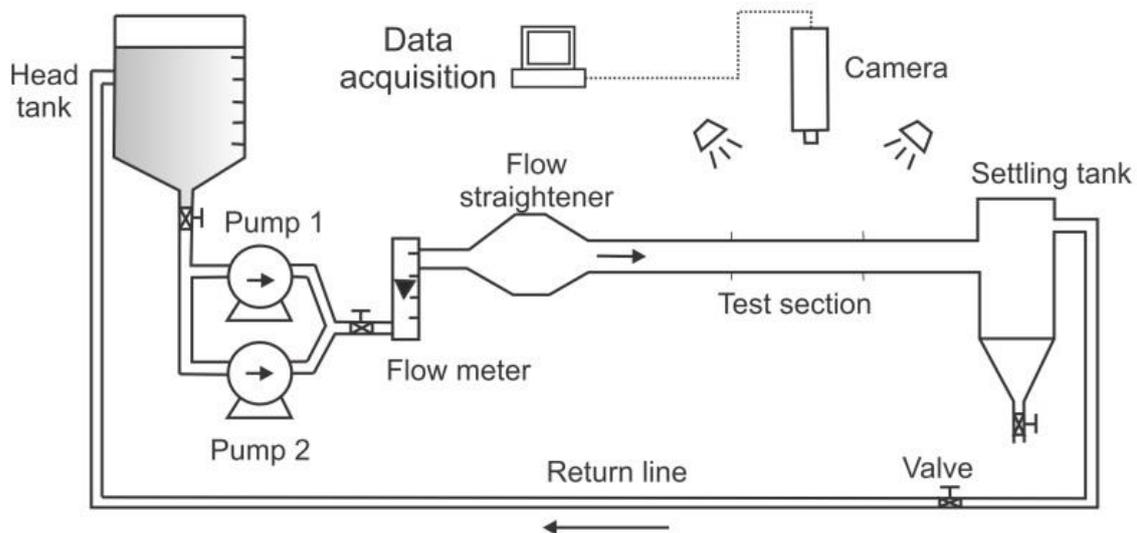


Figure 1. Layout of the experimental setup. Figure extracted from Assis and Franklin (2020).

Round glass beads ($\rho = 2500 \text{ kg/m}^3$) with $0.40 \text{ mm} \leq d \leq 0.60 \text{ mm}$ were used. To follow the particles, 3% of the total mass of each pile were tracers (the same particle with distinct color). To acquire the images, a conventional camera of complementary metal-oxide-semiconductor (CMOS) type was placed above the test section. The camera had a maximum resolution of $1920 \text{ px} \times 1080 \text{ px}$ at 60 Hz. The water flow rate varied from $Q = 7 \text{ m}^3/\text{h}$ to $Q = 8 \text{ m}^3/\text{h}$, which correspond to cross-section mean velocities of $U = 0.24$ and 0.28 m/s , respectively. The Reynolds number based on channel height varied from 12153 to 13900. Matlab codes were written to track particles over time.

3. PRELIMINARY RESULTS

As preliminary results, we could track the tracers over interacting dunes for three different patterns. Figures 2(a), 2(b), and 2(c) show some trajectories of the particles for monodisperse dunes for the exchange, chasing, and merging patterns, respectively. To quantify the dynamics of particles during these interactions, we computed the mean displacements and velocities. Figures 3(a) and 3(b) show probability distributions for longitudinal and transverse displacements while figures 3(c) and 3(d) show distributions for mean velocities for the chasing pattern. The other patterns described before (merging and exchange) as well as dunes composed of a bidisperse mixture of particles are still being analyzed at the present moment.

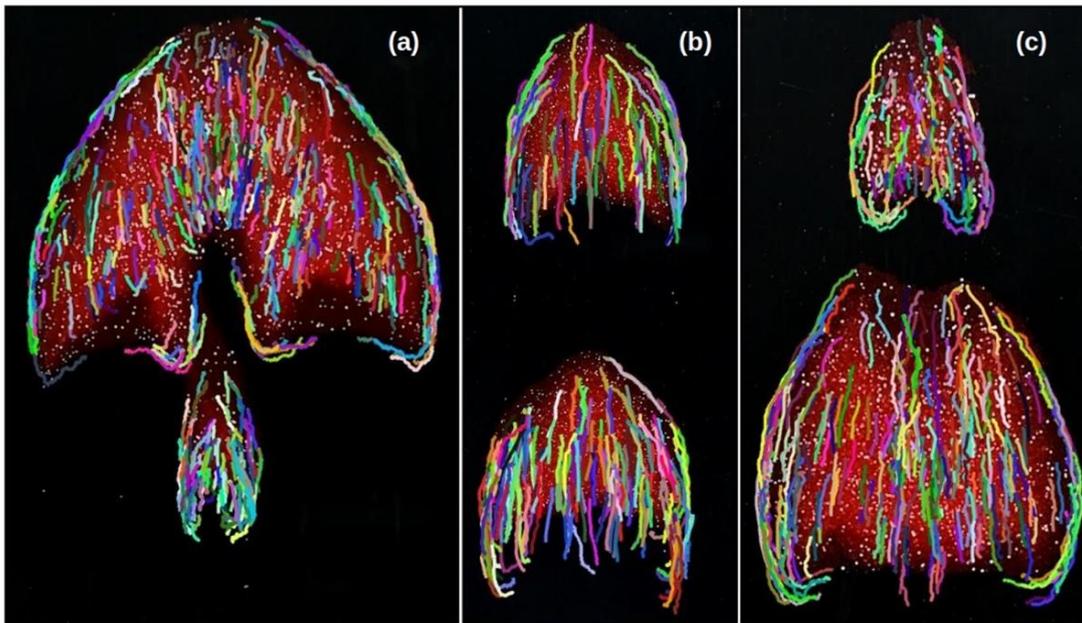


Figure 2. Trajectories of some particles during interaction. (a) Exchange, (b) chasing and (c) merging.

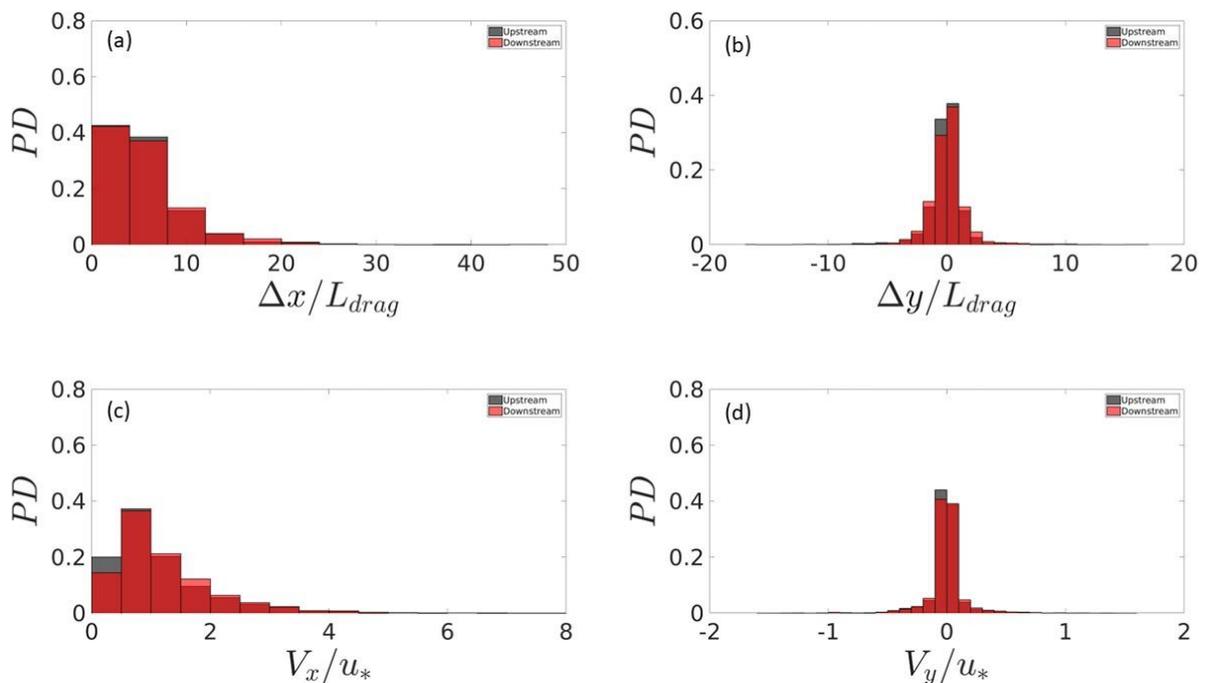


Figure 3. Probability distribution for chasing pattern. (a) and (b) longitudinal and transverse displacements, (c) and (d) longitudinal and transverse velocities.

$$\rho_{mv} = \frac{33.3N_{mv}}{N_{im}A_p} \quad (1)$$

$$\varphi = \rho_{mv}\bar{V}_x m_p \quad (2)$$

Although the distributions are similar, the mean longitudinal velocity (figure 3(d)) of the upstream dune is around 10% smaller when compared to the downstream dune. The data was normalized by the shear velocity over the bottom wall (undisturbed flow), measured with PIV (Assis and Franklin (2020)). Even with the particles showing a higher mean velocity, another point of interest is to understand the number of particles that are moving over the dunes during the process. To compute this, we use equation 1, based on Wenzel and Franklin (2019), where N_{mv} is the total number of moving tracers identified in all images, N_{im} is the total of images analyzed, and A_p is the projected area of the dune. Therefore, ρ_{mv} is an approximation of the density of moving grains. Finally, with the previous data, we can compute the sediment flux over dunes during different interactions. We used equation (2) based on Pächt et al. (2013), where m_p is the particle mass, \bar{V}_x is the average particle velocity in the longitudinal direction, and φ is the sediment flux. The downstream dune presented 64% higher movement density and 58% higher sediment flux when compared with the upstream dune of the same size. This corroborates the non-collisional process when dunes have similar masses (Assis and Franklin (2020), Bacik et al., (2020)). As observed in Wenzel and Franklin (2019), the particles over dunes have an intermittent motion, which implies two timescales in this process: the displacement and stopping times. In this study, we found that the ratio between displacement and stopping times is 0.2 for both upstream and downstream dunes.

Although the results so far are preliminary, they can help us to better understand the displacements of particles in different interactions. We are still analyzing the particle displacements over dunes during the interactions for both monodisperse and bidisperse dunes (two types of particles within the same dune). This information will provide us data about the different particle velocities, and the relationship between them and dune velocity in the different interaction processes.

4. ACKNOWLEDGEMENTS

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