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# BARCHAN-BARCHAN INTERACTIONS WITH BIDISPERSE GRAINS

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***Abstract.*** *Barchans are dunes of crescentic shape with horns pointing downstream which are formed in areas of unidirectional fluid flow and a limited amount of granular material. Fields of barchans are found in deserts, rivers, the bottom of oceans, and even in extraplanetary environments, and the regulation of their size involves the interaction between different barchans within a field. In a recent work (Assis and Franklin (2020)), we investigated experimentally the short-range binary interactions of subaqueous barchans, including collisions, in both aligned and off-centered configurations of dunes with monodisperse grains. As a result, we identified five interaction patterns for both aligned and off-centered configurations and proposed two maps that provide a comprehensive classification for barchan-barchan interactions based on the ratio between the number of grains of each dune, Shields number, and alignment of barchans. The aim of the present study is to investigate the motion and interaction between two barchans with different particle sizes. The experimental setup consisted of a 5 m long closed-conduit channel with a rectangular cross-section (width $\gamma$ = 160 mm and height $\beta$ = 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 afterward deformed into barchan dunes. The particles were glass spheres divided into two different populations of different diameters, but with the same density, and they formed initially two bidisperse piles. The upstream pile was always smaller or equal than the downstream one, since the dune velocity varies inversely with its size, so that dunes interacted actively during the experiments. As preliminary results, we could observe that the proportion of grains of different diameters within the dune can affect the type of interaction pattern. Furthermore, we propose a characteristic collision time, which relates the distances between the dunes, the imposed flow velocity, the initial sizes of the dunes and the proportion of particles.*

***Keywords:*** *barchan-barchan interactions, dunes, bidisperse grains*

## 1. INTRODUCTION

Granular media form a broad family composed of grains of different shapes, materials and sizes (Andreotti *et al.* (2013)). When there is an interaction between a granular media and a fluid flow, different types of bedforms show up. When there is a limited amount of particles and a predominantly unidirectional fluid flow, a specific type of dune, called barchan, appears (Bagnold (1941)). We can find barchan dunes on several environments, such as, deserts, rivers, bottom of oceans and also on the Martian surface.

Several studies have been developed to understand the behavior of barchans (Claudin and Andreotti (2006); Hersen *et al.* (2004); Norris and Norris (1961)). The studies started taking field measurements of aeolian barchans, based on aerial images (Vermeesch (2011); Hugenholtz and Barchyn (2012)). However, due to the time scale of formation and interaction of aeolian dunes being in the order of decades, the data collected is often incomplete. An alternative to reduce the time and length scales to seconds and millimeters, respectively, is to carry out studies of subaqueous dunes (Endo *et al.* (2004); Hersen and Douady (2005)).

Although barchan dunes are studied as isolated objects (Alvarez and Franklin (2017); Alvarez and Franklin (2018)), they belong to dune fields, where they can influence and be influenced by other dunes with different sizes and velocities (Bacik *et al.* (2020); Génois *et al.* (2013)). Endo *et al.* (2004), using a water tank with subaqueous barchans identified some of patterns emerged from binary interactions in the case of aligned barchans for different mass ratios. Also, Hersen and Douady (2005), investigated the off-centered collision with different offsets between dunes. However, how the diameter and density of the particles, the flow velocity, the distances and mass ratio between dunes affect the patterns generated by the interations were still unanswered questions.

In a recent paper (Assis and Franklin, 2020), we investigated experimentally the short-range binary interactions of subaqueous barchans, including collisions, in both aligned and off-centered configurations of dunes. As a result, we identified five interaction patterns for both aligned and off-centered configurations and proposed two maps that provide a comprehensive classification for barchan-barchan interactions based on the ratio between the number of grains of each dune, Shields number and alignment of barchans.

Recently, Alvarez *et al.* (2021) investigated experimentally the growth of subaqueous barchans with bidisperse grains. As results, they showed that a transient stripe appears on the dune surface and the grains segregate with a diffusion-like mechanism. As barchans consist of polidisperse particles, the aim of the present work is to investigate the binary interactions of barchans with bidisperse grains. In addition, we compare the results with those for monodirperse particles and propose a collision time.

## 2. EXPERIMENTS

### 2.1 Experimental device

The experimental setup consisted in a 5 m long closed-conduit channel with a rectangular cross section (width $\gamma$ = 160 mm and height $\beta$ = 50 mm). 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 described experimental setup.

For the test conditions, round glass beads were used ($\rho_s$ = 2500kg/m$^3$) with 0.15 mm $\leq$ d $\leq$ 0.25 mm and 0.40 mm $\leq$ d $\leq$ 0.60 mm. The mass of the entire system was 16g and the proportions ranged from 50% to 2% for the upstream dune and from 50% to 98% for the downstream one. For each test, grains were mixed, forming the initial pile of particles. The mixing ratio of particles was always kept at 50% of each diameter.

The upstream pile was always smaller or equal than the downstream one, since the dune velocity varies inversely with its size, so that dunes interacted actively during the experiments. The water flow was Q = 9 m$^3$/h which correspond to a cross-section mean velocity of $\overline{U}$ = 0.31 m/s and to Reynolds number based on channel height $Re = \rho\overline{U}\beta/\mu$ of 1.56 $\times$ 10 $^4$, where $\rho$ is the density and $\mu$ is the dynamic viscosity of the fluid. To acquire the images, a conventional camera of the complementary metal-oxide-semiconductor (CMOS) type was placed above the test section. The camera had a maximum resolution of 1920 px x 1080 px at 60 Hz, which were the ROI and frequency set in the tests.

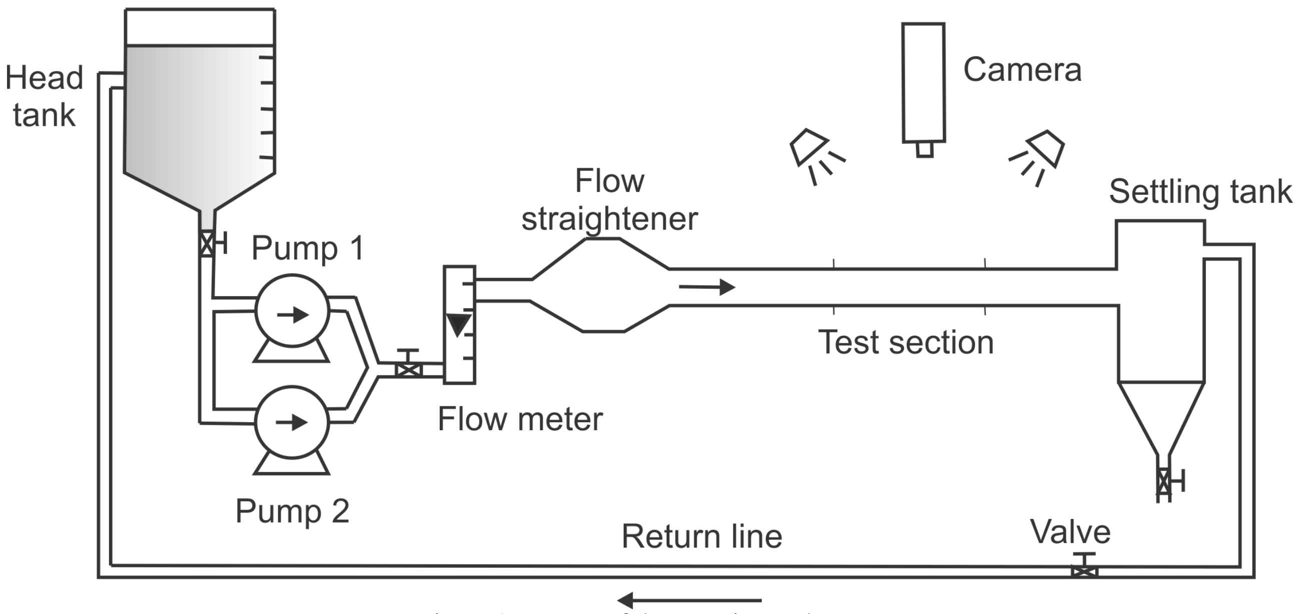
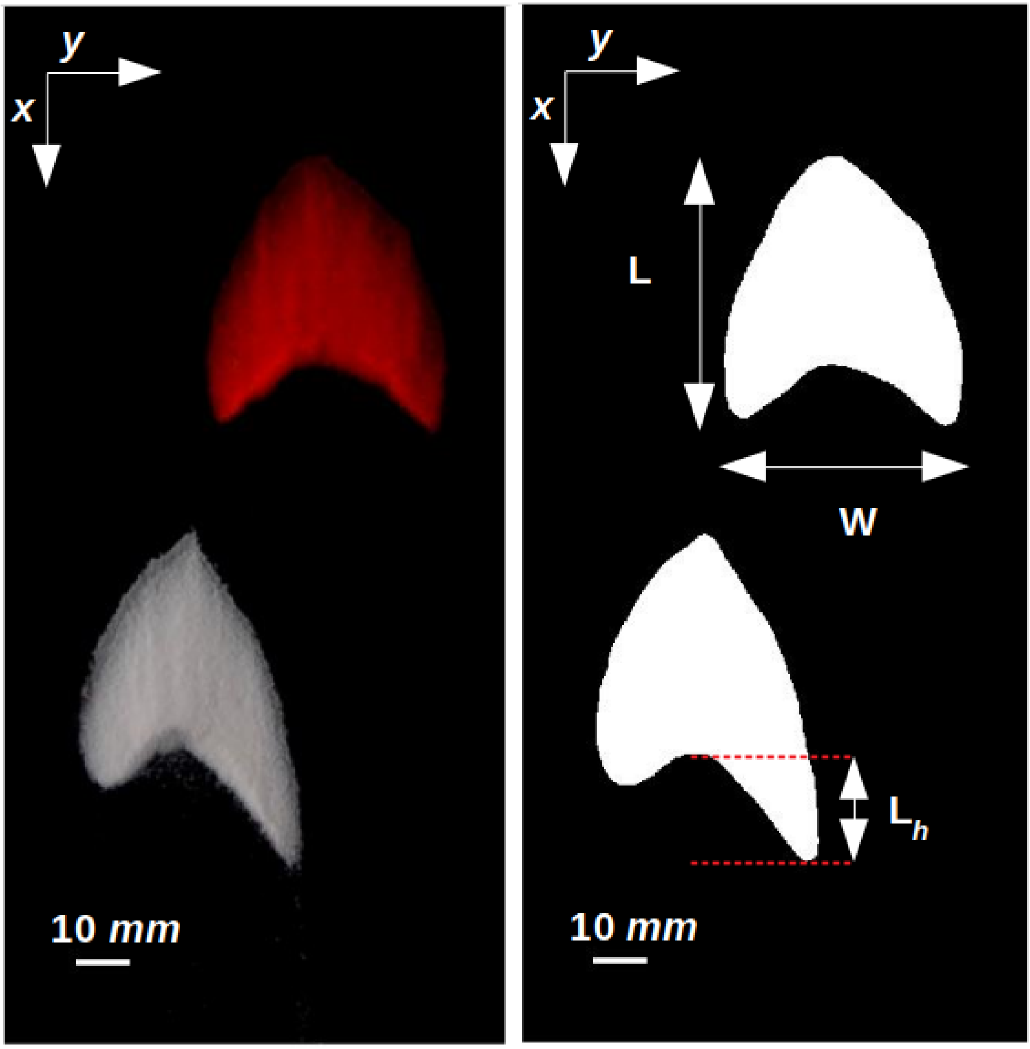



Figure 1: Layout of the experimental setup.

### 2.2 Image Processing

After the acquisition of the images by the camera, the treatment of the images was carried out using the MatLab software. Codes were written to detect the morphological measurements of the dunes and track them through time. Basically, the image background was subtracted and binarized. Values of width (W), length (L) , length of horns ($L_h$) and area were computed. Figure 2 shows an example of image processing with morphological measurements.




(a) (b)

Figure 2: Example of image processing. (a) Original image and (b) image treated with the identified morphological measurements.

## 3. PRELIMINARY RESULTS

### 3.1 Patterns for dune-dune interaction with bidispersed grains

As a preliminary result, the first step was to observe if there is any change in the patterns of dune-dune interactions when there is the presence of two types of particles within the bed. In the simplest case, where there is only a difference in particle size and with a proportion always kept at 50% of each species used, the patterns observed in Assis and Franklin (2020) remained the same. Figure 3 shows the five patterns observed during barchan-barchan interaction with bidispersed grains: 1) Merging (Figure 3a), when the upstream dune reaches the downstream one and they merge; 2) Exchange (Figure 3b), after the upstream dune collides with the downstream one, a small barchan is ejected and migrates downstream; 3) Fragmentation-Exchange (Figure 3c), due the wake of the upstream dune (Palmer *et al.* (2012)), the downstream dune starts to split, but before the splitting process was completed, the upstream one collides. After collision, a small barchan is ejected; 4) Fragmentation-Chasing (Figure 3d), the same process of splitting ocourrs and the downstream one divides into two dunes. Because the divided dunes are smaller than the upstream one, they outrun the upstream dune; 5) Chasing (Figure 3e), when the upstream dune does not reach the downstream one. Chasing pattern appears when the barchans have similar sizes.

Another point observed in this study is about the segregation of species when there is dune-dune interaction. The diffusion-like mechanism in a single dune, which was presented in Alvarez *et al.* (2021), remains the same with the presence of another dune. The transient stripe transverse to the flow direction appears on the dune surface as shown in figure 2e (25s) and figure 2a (16s), for instance.

Finally, in addition to the parameters reported in Assis and Franklin (2020), on which the interactions between dunes

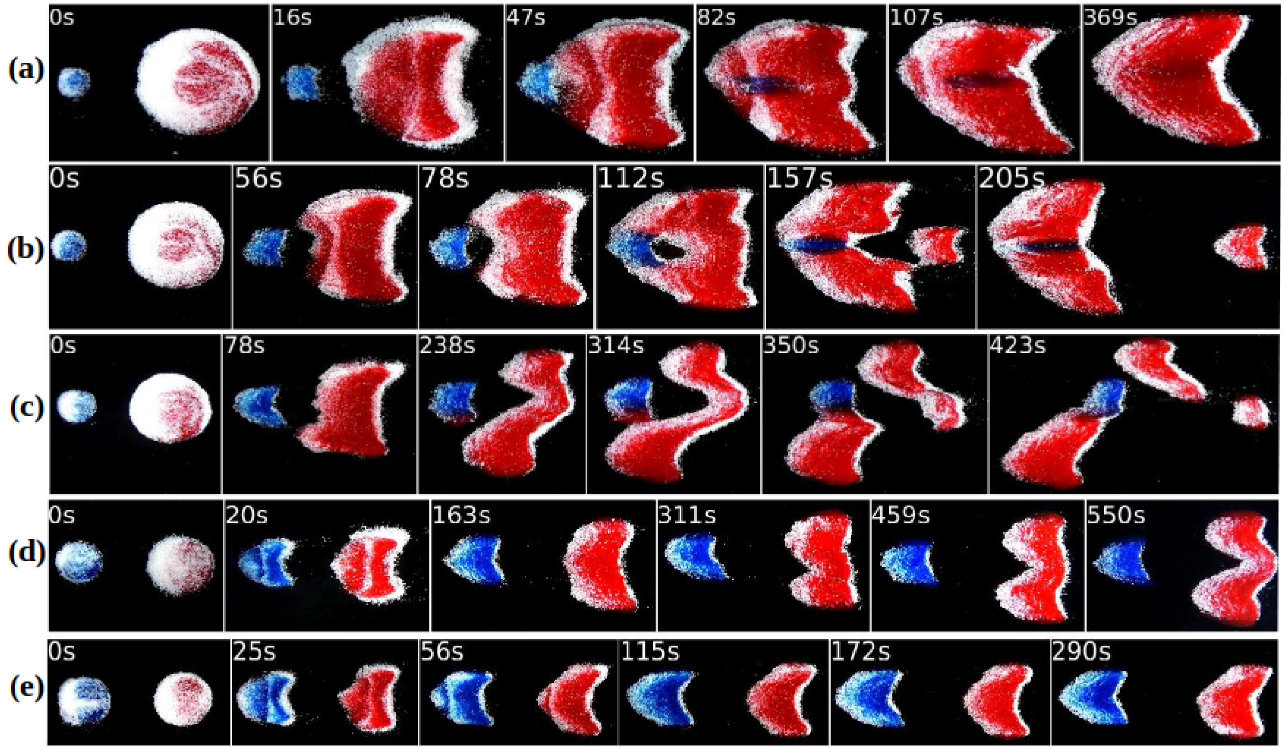



Figure 3: Snapshots of barchan interactions with bidisperse grains. The water flow comes from left to right. Blue and red colors represent smaller diameter particles while white color represents larger ones.

depend, the patterns are now also related to the proportion of particles present in the bed. In the case of 50% of each specie of particle present in the dune, the patterns remained the same as previously observed. However, we observed that with the change in the proportions of particles, new patterns of interactions may emerge, which have not yet been reported.

### 3.2 Collision time

Another part of this study that we are carrying out is about the collision time during barchan-barchan interactions. Figure 4 represents the physical parameters related to the collision time, where $W_i$ and $W_t$ are the initial widths of the impact and target dunes, respectively. Also, $\alpha$ is the distance between the borders of the dunes.

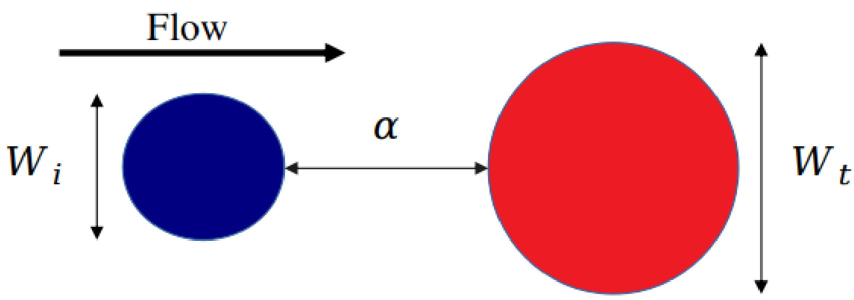



Figure 4: Representation of physical variables involved in the collision time calculation.

The collision time was built as a distance that the impact dune must travel to reach the target one divided by an imposed flow velocity. About the flow velocity, we prefer to use the shear velocity ($u_*$) which is a reference velocity which was measured on the wall of the empty channel. Equation 1 shows the expression of collision time relating $\alpha$ and $u_*$.

$$t_c = \frac{\alpha\delta}{u_*} \tag{1}$$

In addition to that, the collision time also needs to relate the relative movement between dunes ($W_t$ - $W_i$), mean diameter of used particles ($\overline{d}$) and the ratio between particle and flow densities ($\overline{\rho}$). The expressions of $\overline{d}$ and $\overline{\rho}$ are based on Alvarez *et al.* (2021). Equation 2 shows an expression for $\delta$, which relates the variables described before.

$$\delta = \frac{\overline{\rho}}{\overline{d}}(W_t - W_i) \tag{2}$$

Taking all this into consideration, we have measured the time until one dune reaches the other one. Table 1 brings the data from this study for each pattern with bidisperse grains and also the cases from Figure 1 of Assis and Franklin (2020) with monodisperse grains. Our preliminary results show that the collision between barchans occurs when $0 \leq t/t_c \leq 1.5$. Values of $t/t_c$ tend to infinity for non-collision patterns.

Table 1: Morphological measurements for barchan-barchan interactions with monodisperse and bidisperse grains.

| $Mixtures$ | $Pattern$ | $\overline{\rho}$ | $\overline{d}(mm)$ | $u_*(mm/s)$ | $W_i(mm)$ | $W_t(mm)$ | $\alpha(mm)$ | $t(s)$ | $t/t_c$ |
|---|---|---|---|---|---|---|---|---|---|
| Bidisperse | Merging | 2.5 | 0.29 | 17.6 | 18 | 63 | 18 | 29 | 0.1 |
| Monodisperse | Merging | 2.5 | 0.20 | 14.1 | 15 | 86 | 13 | 52 | 0.1 |
| Bidisperse | Exchange | 2.5 | 0.29 | 17.6 | 24 | 61 | 23 | 75 | 0.2 |
| Monodisperse | Exchange | 2.5 | 0.20 | 15.9 | 15 | 75 | 15 | 32 | 0.0 |
| Bidisperse | Frag-Exchange | 2.5 | 0.29 | 17.6 | 27 | 56 | 20 | 290 | 1.0 |
| Monodisperse | Frag-Exchange | 2.5 | 0.20 | 14.1 | 23 | 64 | 18 | 981 | 1.5 |
| Bidisperse | Frag-Chasing | 2.5 | 0.29 | 17.6 | 30 | 43 | 30 | $\infty$ | $\infty$ |
| Monodisperse | Frag-Chasing | 2.5 | 0.20 | 15.9 | 30 | 64 | 22 | $\infty$ | $\infty$ |
| Bidisperse | Chasing | 2.5 | 0.29 | 17.6 | 48 | 50 | 39 | $\infty$ | $\infty$ |
| Monodisperse | Chasing | 2.5 | 0.50 | 15.9 | 63 | 71 | 33 | $\infty$ | $\infty$ |

Although the results so far are preliminary, they can help us to better understand the displacements and interactions of dunes when there is more than one species present in the bed. For the next steps, we will analyze the displacements of particles over the dunes during the interaction process. This information will provide us data about the different particle velocities and the relationship between them and dune velocity in the collision processes.

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