

## ENCIT-2018-0428 Velocity fields of grains over barchan dunes

João Luiz Wenzel<sup>1</sup>

Erick de Moraes Franklin<sup>2</sup>

University of Campinas – UNICAMP

School of Mechanical Engineering,

Rua Mendeleev, 200 – CEP 13083-860 – Campinas – SP

<sup>1</sup> jl\_wenzel@hotmail.com

<sup>2</sup> franklin@fem.unicamp.br

**Abstract.** This paper presents an experimental investigation of the field of grain velocities over subaqueous barchan dunes. The dunes were formed from initially conical piles consisting of spherical glass beads of known granulometry, and 2% of particles are tracers. In the beginning of each test run a determined mass of grains was placed on the bottom wall of a rectangular channel and it was entrained by a water turbulent flow. The experiment was filmed with a high-speed camera placed above the channel. An image processing code was written to determine the displacement of grains with an Eulerian approach.

**Keywords:** Barchan Dune, Eulerian Approach, transport of solid particles, turbulent flow

### 1. INTRODUCTION

The interaction between fluids and granular media can be observed in nature and in human activities. When shear stresses exerted by the fluid on the bed of particles are bounded to some limits, a mobile layer of particles known as bed load takes place. In bed load, the moving particles stay in contact with the fixed bed.

In industry, the bed-load transport occurs in petroleum pipelines conveying grains, in sewer systems and in dredging lines, where ripples and dunes may appear. In a closed-conduit flow, these forms create supplementary pressure losses and pressure and flow rate transients, making it difficult to operate and increasing the operational costs (Franklin, 2016).

In nature, the bed load phenomenon is commonly found in deserts, where the action of wind upon the grains creates the sand dunes. One kind of these dunes is the barchan dune, which are formed under one-directional flow in places with limited sediment supply from the bed or a non-erodible ground, and it has a remarkable crescentic shape with horns pointing downstream (Herrmann and Sauermann, 2000). Bagnold (1941) studied the transport of sand in deserts and the dynamics of desert dunes.

In addition to their common presence in arid environments on Earth, they have also been observed in submarine environments (Todd, 2005) and on Mars (Bourke et al., 2006). The aquatic dunes observed on the bed of some rivers are another example. Barchan dunes under water have received much less attention than aeolian dunes, and important issues remain unanswered (Franklin and Charru, 2011).

The aim of this work is to determine the displacements and velocities fields of moving grains over the subaqueous barchan dune. In order to achieve it, the dune was filmed with a high-speed camera and the images were post-processed with scripts developed by the author.

### 2. EXPERIMENTAL SET-UP

The experimental is the same as used in Alvarez and Franklin (2017). The device consisted of a water reservoir, two centrifugal pumps, a flow straightener, a 5 m long channel, a settling tank, and a return line. The flow straightener was a divergent-convergent nozzle filled with  $d = 3$  mm glass spheres, the function of which was to homogenize the flow profile at the channel inlet. The channel was made of transparent material and had a rectangular cross-section (width = 160 mm and height  $2\delta = 50$  mm). To ensure the complete development of the turbulent water flow, the channel test section started 40 hydraulic diameters (3 m) downstream of the channel inlet, and it was 1 m long. The particles were placed in the channel test section, which was previously filled with water. The grains settled in the water at rest and formed a conical heap. Next, a water flow was imposed in the channel, and the heap deformed into a barchan dune. After the barchan dune was formed, the displacement of the tracers over the dune was recorded with a high-speed camera placed above the channel.

In the experiments, water was used as the fluid media and some spherical beads as granular material: glass beads with density  $\rho_s = 2500$  kg/m<sup>3</sup> and diameter range between  $d = 0.4$  mm and  $d = 0.6$  mm. Two percent of grains are of

different color, which we consider as tracers, in order to make it easier to identify in images. The water flow rate was varied between 6.7 and 10.5 m<sup>3</sup>/h. The flow velocity  $U$ , defined as the ratio of the measured volumetric flow rate and the channel cross-section, was varied between 0.2 and 0.36 m/s. The corresponding Reynolds number was calculated using the Eq. 1 and it was in the range 11600 – 18200.

$$Re = \frac{\bar{U}2\delta}{\nu} \quad (1)$$

where  $\nu$  is the kinematic viscosity

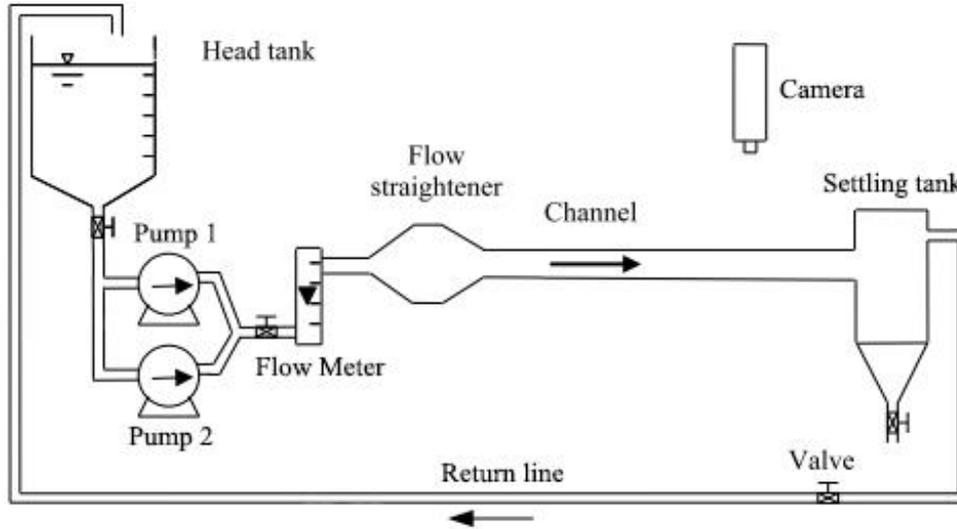


Figure 1: Layout of the experimental device

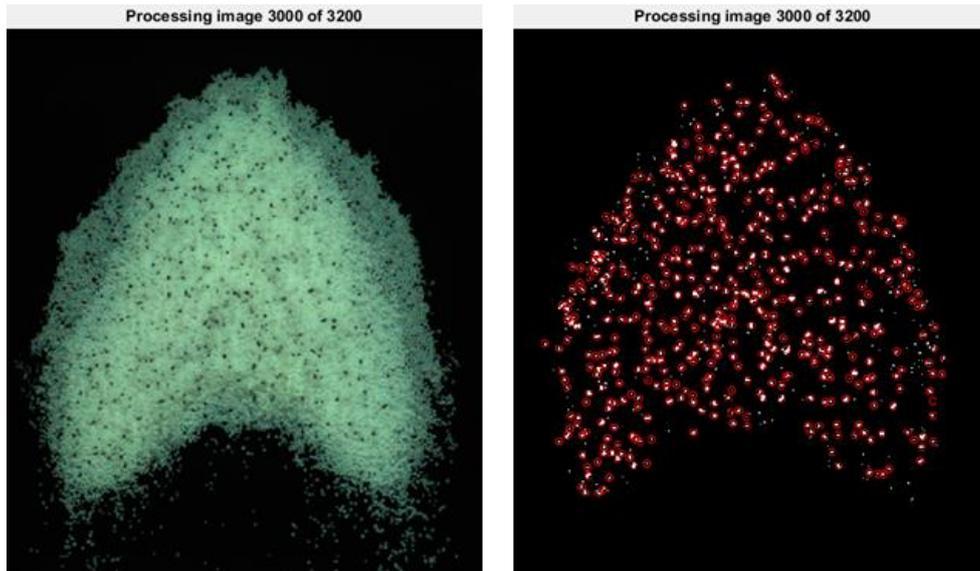
## 2.1 INSTRUMENTATION

A high-speed camera mounted in a travelling system, with a resolution of 1280px × 1024px at frequencies that can reach 1000 Hz, was employed to obtain the displacements of grains. For each test run the maximum number of images that were recorded in sequence was 3200, this number is a ratio of the camera's internal memory by the region of interest (ROI) selected in the image. The ROI used was 800px x 1024px, it was determined to ensure an optimal framing of the dune, and frequency was adjusted between 50Hz and 300Hz accordingly to the flow velocity.

A computer was used to control the frequencies, exposing times, position of the high-speed camera and to save the acquired images. Because of the high frequencies used, an intense illumination was required, and it was provided by LED (low emission diode) plates branched to a continuous electrical source. The calibration process was made by inserting a scale in the test section. This allowed the pixels to metric system conversion.

## 3. IMAGE PROCESSING

Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it. To render the image in a more suitable form to machine perception, the main step is to transform the true color RGB (red, green and blue) image in gray-scale format (Penteado and Franklin, 2016). This task can be done using the weighted method, that basically returns the mean value between the red, green, and blue channel of the picture. As the result, each image is a two-dimensional matrix with the brightness of the image at any given point. Usually they assume only integer values; therefore, the image will have lines and columns ranging from 1 to 256 each, corresponding to brightness values ranging from 0 (black) to 255 (white). Figure 2(a) shows the raw image, and figure 2(b) shows the processed image.



**Figure 2. (a) Raw image; (b) Processed image**

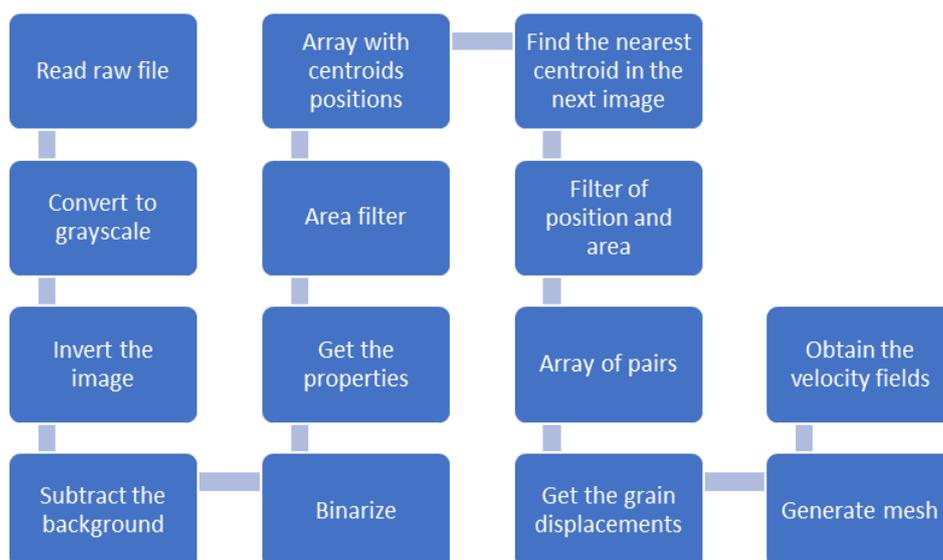
It is possible to obtain the position of the tracers by applying some filters, such as threshold values of pixel intensity and area, and background removal.

### 3.1 CODE ALGORITHM

The first steps are to read the RGB image, convert it to grayscale, and, due the fact that the tracers are black, it is necessary to invert the image, which makes the tracers more detectable to computer. Next, the background of the picture is removed. This is made using a function that identifies and suppresses each pixel connected to image border.

In the following, the file is binarized by using a brightness threshold given by the Otsu's method. The binarization allows to obtain the properties of the objects in the image. However, not all identified objects are tracers, some of them are experimental noise caused by small changes in illumination, or small movements between the frames. To solve this issue, an area filter is applied, then each picture results in an array of centroids positions of tracers.

The last step is to identify the same grain in the subsequently frame, here the code looks for the nearest centroids positions. In order to enhance the code accuracy, two filters are applied: area and position filters. As the result, an array of pairs is obtained, consequently it is possible to determine the grains displacements, generate a mesh, and get the velocity fields.



**Figure 3: Flowchart of code algorithm**

#### 4. RESULTS

The displacement of the grains over a subaqueous barchan dune entrained by a turbulent water flow was analyzed using an Eulerian approach. Our results show that the velocities of the grains are higher in the center of the dune, where, because of its shape, the grains are exposed to a higher water velocities. Figure 4(a) shows the velocity fields of five consecutive frames, figure 4(b) shows the mean velocity fields of 2000 consecutive frames.

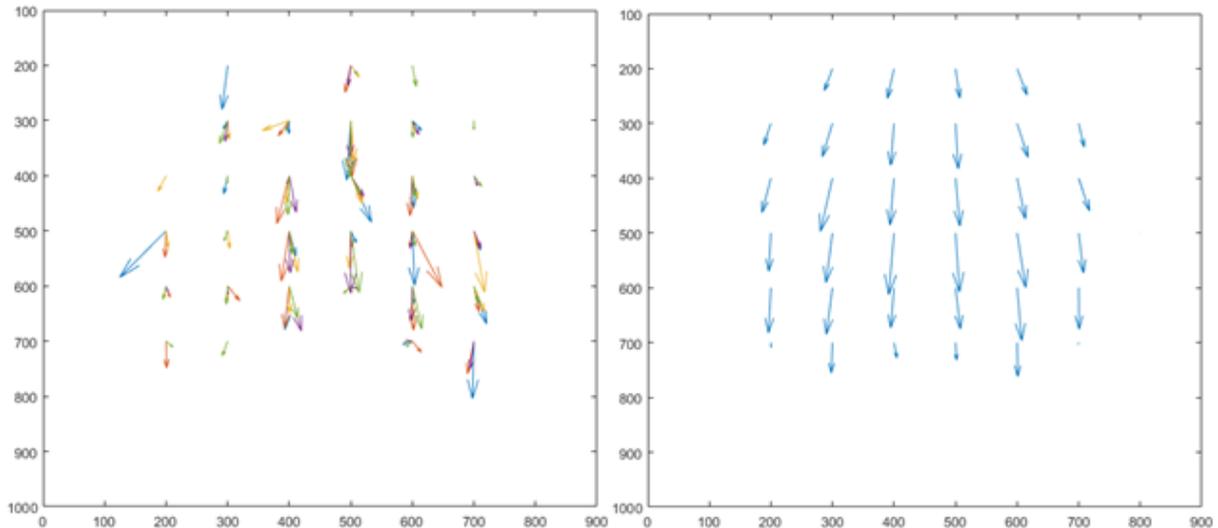


Figure 4. (a) Velocity fields of 5 images; (b) Average velocity fields of 2000 images

#### 5. CONCLUSION

The present work reports the grains displacements over the barchan dune. The experiments were filmed with a high-speed camera, and a script was developed to process the image. By applying some filters, it was possible to determine the position of the grains along the frames. In this way, the displacement of the tracers was obtained, a mesh was generated, and we determined the grain velocities.

#### 6. ACKNOWLEDGEMENTS

The authors are grateful to FAPESP (grant no. 2016/13474-9), to CNPq (grant no. 400284/2016-2).

#### 7. REFERENCES

- Alvarez, C.A. and Franklin, E.M., 2017. "Formation and morphology of subaqueous Barchan dunes" In *Proceedings of the 24th International Congress of Mechanical Engineering - COBEM2017*. Curitiba, Brazil.
- Bagnold, R.A., 1941. *The physics of blown sand and desert dunes*. Chapman and Hall, London, United Kingdom, 320 p.
- Bourke, M.C., Balme, M., Beyer, R.A., Williams, K.K., Zimelman, J. 2006. "A comparison of methods used to estimate the height of sand dunes on Mars". *Geomorphology*, v. 81, n. 3-4, p. 440-452.
- Franklin, E.M. 2010. "Initial instabilities of a granular bed sheared by a turbulent liquid flow: length-scale determination". *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, v. 32, p. 460-467.
- Franklin, E.M. and Charru, F. 2011. "Subaqueous barchan dunes in turbulent shear flow. part 1. dune motion". *Journal of Fluid Mechanics*, Vol. 675, pp. 199-222.
- Herrmann, H.J. and Sauer mann, G. 2000. "The shape of dunes". *Physica A*, Vol. 283, pp. 24-30.
- Penteado, M.R.M., Franklin, E.M., 2014. "Bed load under a turbulent liquid flow". In *Proceedings of the 15th Brazilian Congress of Thermal Sciences and Engineering - ENCIT2014*. Belém, Brasil.

## **8. RESPONSIBILITY NOTICE**

The authors are the only responsible for the printed material included in this paper.