EXPERIMENTAL STUDY ON THE MODULATED AEOLIAN BARCHAN DUNE

Yang Zhang[*], Yuan Wang[*a)] & W. van de Water[**]
[*]*Department of Fluid Machinery & Engineering, Xi'an Jiaotong University, Xi'an, 710049, China*
[**]*Department of Applied Physics, Eindhoven University of Technology, 5600 MB Eindhoven, the Netherlands*

Summary An experiment is carried out to study the scale-down unsaturated barchan dune in the wind tunnel under two modulations: the excitement of sand grains by oscillation and the upwind influx. A top-view camera is applied to record the dune evolution and a combination of image processing algorithms is used to abstract the characteristic lengths representing the dune configuration. One can conclude from the results that the invariant and asymptotic behaviours of dune configuration in the transverse and windward directions respectively could offer an approximate but intuitive understanding of the dynamics of dune evolution.

INTRODUCTION

As one of the most fascinating phenomena in the natural world and a kind of sand pattern driven by the uniformly directed wind, the barchan dune has been extensively investigated by means of numerical simulation and field observation [1]. Its evolution is mainly attributed to the interaction among the dune configuration, the air flow and the surface shear stress [1] in which the saltation performs to distinguish the aeolian dune from its subaqueous counterpart [2]. However, both the temporal and spatial scales of its evolution make it very hard to achieve a thorough field observation. An experiment in the laboratory is thusly developed to track the entire evolution of scale-down dune. Owing to the strict conditions in preserving a constantly migrating dune (such as the saturation length described by Kroy et al. [1]), this work is about the morphological features [2] of unsaturated crescent-shaped dune under different modulations.

EXPERIMENT & DATA PROCESSING

Experimental setup

As shown in Fig. 1, a replicable conical sand heap is placed downwind of the exit of the wind tunnel. A gird is fixed at the exit to generate a turbulent boundary layer above the plate where the logarithmic wind profile can be found. Two different modulations are applied to this wind-blown sand system. Upwind of the sand heap, a mechanism of sand supply is realized by pushing the sands up to the surface through a slot with a band constantly wrapped around an electric axis, and the supplying influx q_{sup} can be quantified collectively by the rotating speed of the axis and the slot area. On the other hand, the plate holding the sand heap is capable of oscillating vertically in a trigonometric way: $y=A\cos\omega t$, in which y, t, A and ω are the vertical distance of the plate from its original position, the time, the magnitude and the frequency of oscillation, respectively. Given the quantifying parameter $\Gamma=A\omega^2/g$ the instantaneous effective acceleration of sand grain is modulated as $g_{eff}=g(1-\Gamma\cos\omega t)$, in which g is the acceleration of gravity.

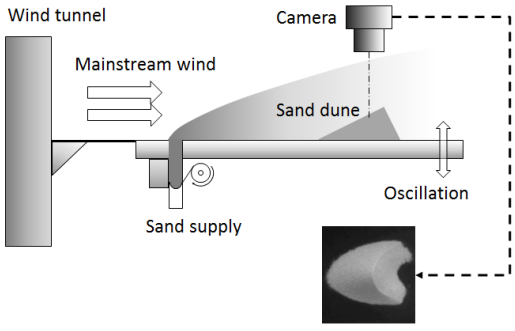

Fig. 1 Schematic of the experiment

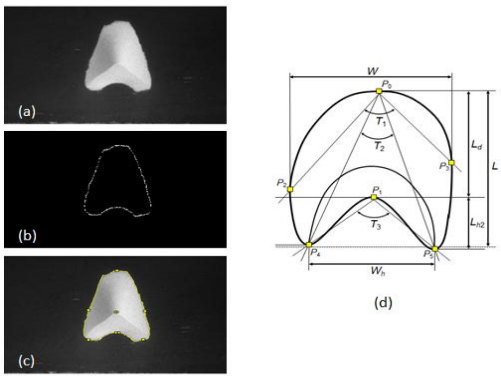

Fig. 2 Processing of the dune image

A digital camera is placed on top of the heap to record the dune projection on the plate. The frame rate of the camera is settled as same as the oscillation rate (7 Hz, determined by the limit of experimentation and the need to obtain a distinct gravity modulation) to eliminate the influence of oscillation on the image quality. In each case 1000 consecutive frames are recorded under a mainstream wind of 6 ms^{-1} (and the friction velocity equals 0.18 ms^{-1}). Γ varies from 0.2 to 0.8

[a)] Corresponding author. Email: wangyuan@mail.xjtu.edu.cn

(increased by 0.2) at a constant q_{sup}=1.5 gm^{-1}s^{-1} in investigating the modulation of gravity while q_{sup} varies from 1.63 to 6.52 gm^{-1}s^{-1} (increased by 1.63 gm^{-1}s^{-1}) at a constant Γ =0.2 in investigating the modulation of influx.

Image processing

Due to the strong contrast between the dune body and the background (Fig. 2a), for each frame the dynamic threshold grey scale can be easily calculated in the first place to abstract the dune body and subsequently the dune contour (Fig. 2b). By setting the centre of contour as the origin of a polar coordinate one can get the characteristic points $\{P_i\}$ of the dune body by finding the set points on the "contour curve" in the polar coordinate (Fig. 2c). Then all characteristic lengths of dune body can be defined with $\{P_i\}$ (Fig. 2d).

RESULTS AND DISCUSSION

The objective of this work is to investigate the change of characteristic lengths representing the mass and the configuration of dune along the linear increase of the modulations. The supplying sands from upwind hit the windward face of the heap and propel more grains into the wind. Similarly, the modulation of gravity by oscillation is a common way to decrease the threshold for the lift-off of grains [3]. However the small grain diameter (200μ m) guarantees the compactness of the dune shape during the evolution rather than a random jumping of all grains. Therefore both modulations work to erode the sand dune and their effects on the dune shape are similar to each other. Limited by the range of manuscript, only the results concerning the effect of upwind influx on the dune body (without the dune horn) are given here. As shown in Fig. 3a, the transverse dune length W roughly maintains the trend disregarding the influx change. On the contrary, the trend of the square root of dune area L_{a1} (an isotropic length scale representing the mass of dune) and that of stream wise length L vary as being asymptotically convergent. The curve fitting of power function $L=at^m$ (m=1.4~1.6) is applied and its coefficient is used to confirm such convergence (Fig. 3b, c). The invariant and asymptotic behaviours of dune configuration in two dimensions collectively reflect the feature of dune evolution.

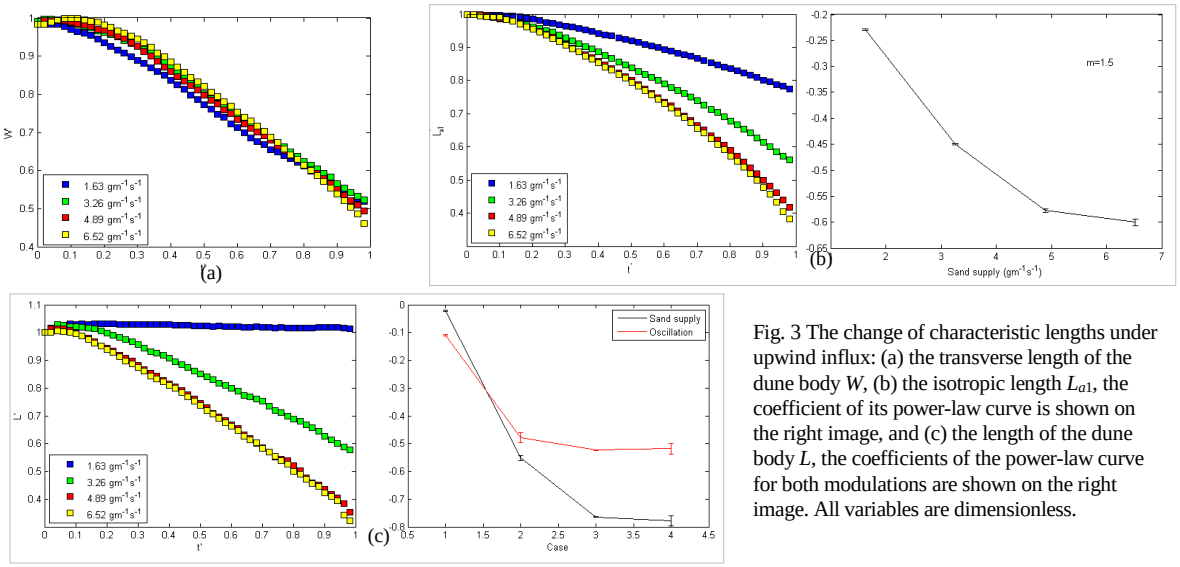

Fig. 3 The change of characteristic lengths under upwind influx: (a) the transverse length of the dune body W, (b) the isotropic length L_{a1}, the coefficient of its power-law curve is shown on the right image, and (c) the length of the dune body L, the coefficients of the power-law curve for both modulations are shown on the right image. All variables are dimensionless.

CONCLUSION

A system of analyzing the dune evolution based on digital image processing technique has been established to give an intuitive description of the variance of two uncorrelated dimensions of dune configuration in responding to the modulations of erosion. The future work may involve the question of similarity to the natural cases. More modulations including the initial condition of dune, the grain size, the friction velocity and the distance between the sand supply and the dune can be applied. Moreover, the third dimension in the plumb line direction can be realized by the side-view imaging to construct a 3D analysis of dune evolution.

References

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