Experimental Measurements of Turbulent Flow Structure Associated with Colliding Barchan Dunes. N. Bristow[1], C. Wang[3], G. Blois[1], J. Best[2], W. Anderson[3], and K. Christensen[1]. [1]University of Notre Dame (nbristow@nd.edu), [2]University of Illinois at Urbana-Champaign, [3]University of Texas – Dallas.

Introduction: Barchan dunes are three-dimensional (3D) topographic features generated by geophysical flows in the presence of sediment mobilized over a hardly erodible substrate and are important in a number of engineering and geophysical applications [1]. While barchan dunes are traditionally associated with aeolian environments on the Earth's surface, satellite imagery has shown their prevalence in the craters of Mars, and high resolution maps of river bed topologies have revealed the occurrence of such dunes in subaqueous environments as well. These observations have sparked inter-disciplinary interest in these bedforms, particularly for their geomorphological, environmental and engineering significance.

Barchans typically occur in fields with significant heterogeneity in dune size and migration rate. In this situation, the interaction between barchans of different sizes produces complex processes such as collision, amalgamation and breeding [2]. While the morphology of barchan dunes has been widely studied, the interaction between turbulent flows and barchans is limited to a few recent studies [3,4]. The number of direct flow measurements is even fewer with respect to the interaction mechanisms occurring when barchans are in close proximity. This lack of data is partially due to the geometric complexity of these bedforms that introduces significant challenges in high-resolution optical flow diagnostic techniques such as particle image velocimetry (PIV). As a result, the processes involved in the collision and breeding of such dunes remains poorly understood and therefore the impact of turbulence is not adequately incorporated in many current numerical models.

In this paper, we study the flow field surrounding idealized, fixed physical models with high-resolution planar PIV. The baseline case of an isolated barchan is compared to several stages of a collision involving a smaller upstream barchan dune (UBD) that is laterally offset from a larger downstream barchan dune (DBD). At each stage of the collision processes the morphology of the DBD is modified by elgonating its horn to mimic the asymmetry observed in nature during collisions [5,6].

Methods: Access to the flow field around these geometrically complex dunes is achieved using a refractive index matching (RIM) approach. Transparent models of barchan dunes, whose shape was based upon previous work [3], were fabricated by casting ure-thane material into 3D printed molds. The models were fixed in a RIM flow tunnel that employs an aqueous solution of sodium iodide (~ 63% by weight) as the working fluid, and rendered invisible, thus facilitating unimpeded data collection around the entire bedform system. Planar measurements at high spatial and temporal resolution were conducted in the x-y (i.e. wall-normal) and x-y (wall-parallel) plane at several elevations away from the wall in order to reveal the 3D nature of the flow. An example of these measurements is shown in Fig. 1, where the case of an offset collision is reported. The measurements conducted in this work would be impossible in either a wind or water tunnel owing to laser blockage and/or aber-ration upon light interaction with the barchan models. In contrast, because the refractive indices of the fluid and the solid models are matched precisely in the present experiments, no loss of laser energy or laser deflection is present as light passes through the solid models, while optical aberrations are also minimized.

The work presented here complements Large Eddy Simulations performed at the University of Texas – Dallas in a combined effort to understand the flow physics around these complex bedforms in such a way that the numerics can be validated experimentally.

Results: The single point turbulent statistics obtained from the flow fields provide some insight into the dominant flow features that may be correlated with sediment transport processes. Figure 1 shows a combination of mean streamwise velocity measurements in one wall-parallel plane (at a height of 0.25h, where h is the height of the larger barchan) and one wall-normal plane (at the centerline). Streamlines reveal the ensemble averaged structure of the flow, where a large recirculation region exists in the lee of the dune, extending roughly 4.8h downstream from the crest, ending at the reattachment point. This region of the flow is characterised by low momentum, separated flow moving back upstream at up to $0.3U_{FS}$, where U_{FS} is the mean free stream velocity. The streamlines also show the significant amount of spanwise motion in the leeside.

Contour maps of turbulent kinetic energy (TKE) (Figure 2) and Reynolds shear stress (RSS) show high levels of turbulence being produced from the horns and crest, along the three-dimensional shear layer that develops as flow separates over the leeside. These high concentrations of TKE and RSS extend a significant distance downstream, elevated from the floor, suggesting the impact that an upstream barchan dune would have on the sediment transport associated with a downstream barchan in close proximity.

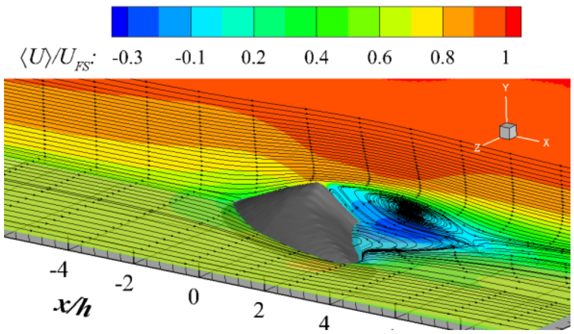

Figure 1: Mean streamwise velocity contours in 0.25h wall-parallel plane and centerline wall-normal plane plotted with streamlines for isolated barchan.

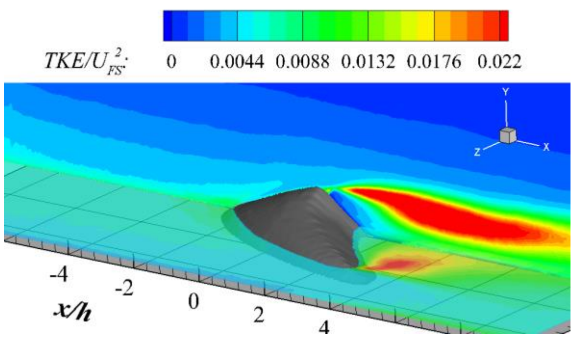

Figure 2: Turbulent kinetic energy contours contours in 0.25h wall-parallel plane and centerline wall-normal plane for isolated barchan configuration.

Indeed, this effect is clearly shown in the subsequent dune-dune collision experiments. As the UBD is introduced upstream, the wake of the DBD develops an asymmetry which grows as the UBD moves closer to the DBD. Flow over the horn of the DBD in-line with the UBD is sheltered by the presence of the UBD, and consequently flow separation over the horn weakens, though the levels of TKE and RSS increase due to the higher levels of turbulence being produced by the UBD. Within the interdune space, flow channeling mechanisms can be seen as well as a strong “wake veering” effects for the UBD (Figure 3). Their behavior is consistent with recently published LES simulations using similar geometries [7].

Our results indicate that the shear layer may have important morphodynamic implications, since it embodies a significant fraction of the RSS and thus plays a central role in the erosion processes induced by the barchans. These measurements are the first step towards linking, in a quantitative fashion, the energy dissipation due to turbulent mechanisms (i.e. shear layers) to localized erosion phenomena (i.e. erosion at the stoss side) that have been highlighted by previous qualitative mobile bed experiments involving interacting bedforms [2].

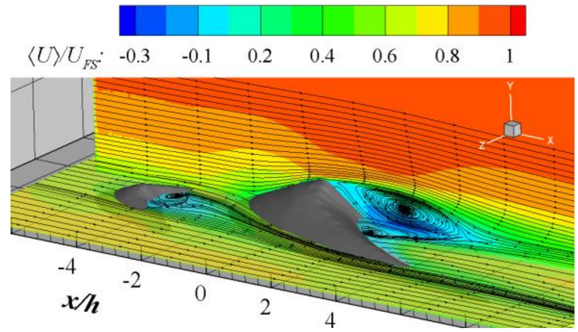

Figure 3: Mean streamwise velocity contours in 0.25h wall-parallel plane and centerline wall-normal plane plotted with streamlines for final collision configuration.

Conclusions: This study provides accurate 2D flow measurements of the turbulent flow surrounding fixed, interacting barchan dune models. Using planar PIV in conjunction with a refractive index matching technique, the mean flow structure around dunes in different configurations was measured and is presented here.

Comparisons of the experimental results shown here and those garnered by LES are underway, including quantitative assessment of the wake-veering phenomena and using observed turbulence phenomena to explain erosion patterns previously observed in nature and lab experiments involving mobile dunes. In addition, fixed-bed models that reflect the morphological asymmetry observed in previous mobile-bed observations are under study by both LES and experiment.

Further work remains to fully extract the dominant flow structures and mechanisms correlating to sediment transport and morphological change associated with these types of interactions. Future experiments to aid in this endeavour include time-resolved and 3D PIV measurements which will help to characterize and resolve important structures in the flow.

References: [1] Lancaster, N. (2009). *Geomorphology of desert environments*, 557–596. [2] Endo, N., Taniguchi, K. & Katsuki, A. (2004). *GRL, 31*, 1-3. [3] Palmer, J.A. et al. (2012) *Exp. Fluids, 52*, 809-829. [4] Charru, F. & Franklin, E.M. (2012) *JFM, 694*,131–154. [5] Hersen, P. & Douady, S. (2005) *GRL, 32*, 1-5. [6] Parteli, E.J.R. et al. (2014) *Aeolian Research*, *12*, 121–133. [7] Wang, C. et al. (2016) *Computers and Fluids*, 1-12