EXPERIMENTAL RESULTS SUPPORTING AN IMPACT-RELATED BLAST WIND FORMATION MECHANISM FOR SOME WIND STREAKS ON MARS.

S. N. Quintana[1], P. H. Schultz[1], and S. S. Horowitz[2], [1]Brown University Department of Earth, Environmental and Planetary Sciences, 324 Brook Street, Providence, RI 02912, [2]NeuroPop, Inc.

Introduction: Different types of wind streaks on Mars can provide a wealth of information about the planet, ranging from global atmospheric wind circulation patterns [1] to impact-related processes that reveal past surface conditions or climate [2, 3]. Wind streaks related to global wind patterns form by an entirely different mechanism than the impact-related streaks radiating from some craters on Mars. Such impact-related "blast wind" streaks are relatively permanent features that may reveal a record of impact conditions and processes at the time of crater formation. The current work details experiments designed to address the underlying formation mechanism for the blast wind streaks on Mars.

Background: Previously, we proposed that such permanent, impact-related blast wind streaks are formed when vapor produced during impact generates intense and sustained winds [2, 3]. These winds are strong enough to entrain surface material, which can cause surface preconditioning and scouring, especially "downwind" from preexisting topography. Blast winds travel great distances from the parent crater at hundreds of meters per second [2, 3]. Reverse winds are also evidenced by some documented wind streak tails pointing back toward the parent crater on Mars.

Both laboratory and numerical experiments have been applied to the study of impact blast winds on Mars [3, 4]. Previous work incorporated computational simulations performed using the CTH shock physics analysis package [5]. These simulations reveal that impact-generated vapor under current Martian surface conditions would induce a strong wind that travels away from the crater at hundreds of meters per second, especially when a layer of ice is present at the surface [3]. Surface obstacles interrupt the boundary layer and enhance vortex development, which suggests that double wind streak tails trailing from existing topographic features may be the result of horseshoe vortex surface scouring [6]. Previous laboratory work documented the initial vapor blast and turbulence at the target surface [3].

The current work details the next step in laboratory experiments. Laboratory experiments are not intended to replicate an actual impact event, but rather they can be used to isolate a particular process or processes for deeper analysis and comparison with numerical codes. The aim of the current study is to resolve the different contributions to impact-generated winds: the contact shock that couples energy to the atmosphere in an air-blast-induced shock wave; the vapor phase acting against the ambient atmosphere; and a possible ground-coupled air shock [7].

Methods: Experiments were performed at the NASA Ames Vertical Gun Range (AVGR) facility in Mountain View, CA. Pyrex projectiles (6.35 mm in diameter) were fired at approximately 5.5 km/s into a powdered dolomite target. The ambient atmospheric pressure in the target chamber at the time of impact was approximately 33.3 hPa (~3.3% of Earth's atmospheric pressure at sea level). Impact angle varied between 30° and 90° with an emphasis on 45° impacts. Three different measurements established the relative roles of each wind-generating process. First, high-speed imaging allowed the analysis of the vapor blast during the early stages of the impact process, as well as later stage mobilization of tracers. Second, an array of PCB Piezotronics pressure sensors placed around the target chamber recorded the timing and pressure jumps resulting from the vapor blast and winds. Finally, an array of microphones and geophones placed in and around the target directly measured the ground shock.

Eight high-speed cameras captured the impact in extreme detail. An assortment of tracers recorded the arrival time and winds created by each impact: dolomite powder and millimeter-diameter Styrofoam balls were sprinkled on the plate; Styrofoam balls were placed on an elevated aluminum pedestal ~75 mm away from the edge of the target bucket (~67cm from the impact point); and dolomite-dusted pipe cleaners were placed within the target, ~50 mm from the edge of the target container. A plate extending nearly to the target allowed tracers to be physically separated from the target container by a small gap.

Results: The various experimental methods allowed the entire process to be captured for the first time. First, the high-speed cameras recorded a surface roughening (Fig. 1) that traveled at supersonic speeds with significant asymmetries as a function of impact angle (Fig. 2). Geophones buried within the target also documented asymmetries related to impact angle but recorded much lower speeds (~270 m/s). Hence, the roughening of the surface is interpreted as an air-coupled shock wave created at first contact, while the signal from the buried geophones is interpreted as the ground-coupled shock wave.

At the same time, a luminous column travels uprange, back up along the original trajectory of the impactor. This column is composed of target vapor filling the vacuum generated by the passage of the impactor through the chamber. Uprange pressure sensors detect a signal, which is expected to be the wake of the impactor. In addition, Styrofoam balls uprange responded to winds generated by the wake blast.

Passage of later-arriving and slower (150 m/s) winds entrained dolomite dust off of pipe cleaners placed vertically in the target (Fig. 3), as captured in high-speed cameras. Moreover, the direction of flow subsequently reversed, consistent with recovery conditions. Consequently, these winds are interpreted to be winds created by the atmosphere in response to the expanding vapor plume.

Previous experiments captured the motion of Styrofoam balls sprinkled on the target surface [3], but it was unclear if the upward and outward movement of the tracers was caused by the air shock, ground-coupled air shock, or the winds coupled to vapor expansion. In the present experiments, these tracers were placed on a plate isolated from the target. The timing and motion of the tracers demonstrated that they moved in response to turbulent winds created by the vapor plume interacting with the atmosphere.

Implications: The clear documentation of the separate components that drive blast winds in laboratory experiments will be used to create a matching computational model. The combination of laboratory experiments and computational models that yield consistent results will provide the confidence to describe and understand the blast wind streaks found on Mars. The extent and morphology of Martian blast wind streaks can help to constrain conditions of the atmosphere and possible presence of near-surface volatiles at the time of impact.

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References: [1] Thomas, P. et al. (1981), *Icarus*, *45*(1), 124–153. [2] Schultz, P. H. and Quintana, S. (2013), *LPSC 44*, Abstract #2697. [3] Quintana, S. and Schultz, P. H. (2014), *LPSC 45*, Abstract #1971. [4] Schultz, P.H. and Wrobel, K. E. (2012), *JGR* 117, E04001. [5] McGlaun, J. M. et al. (1990), *Int'l J. of Impact Eng.*, *10*(1–4), 351–360. [6] Greeley, R., and J. D. Iversen (1985), Mars, Venus and Titan, Cambridge University Press. [7] Cooper, H. F., Jr. (1977), Proc. of the Symposium on Planetary Cratering Mechanics.

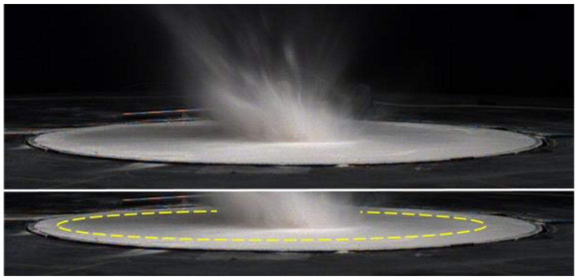

Figure 1 – A 45° impact after ~315 µs showing the progressing surface roughening by the air-coupled shock wave. Yellow circle in bottom image is a guide.

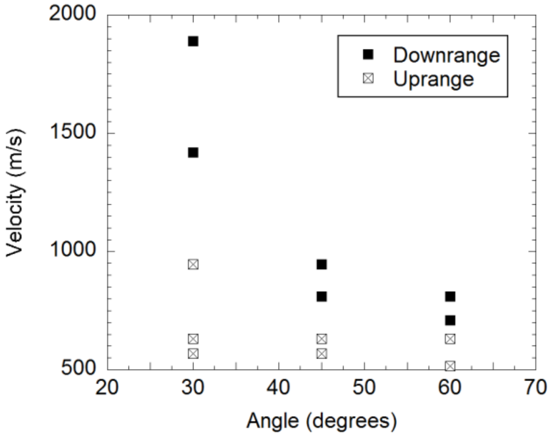

Figure 2 – Plot of downrange and uprange air-coupled shock velocities with respect to impact angle.

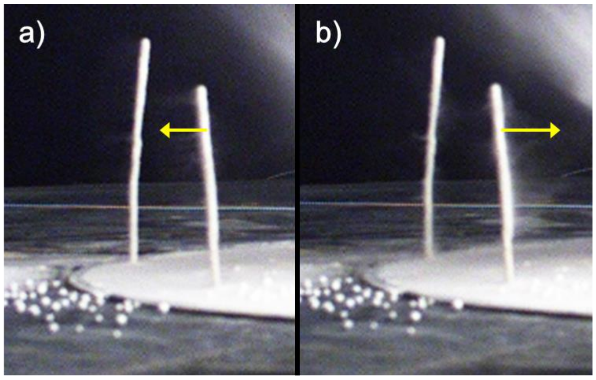

Figure 3 – Blast winds (arrows) blowing dust off of the pipe cleaners. Image is taken from a 45° impact at 5.04 km/s. 2a) Dust mobilized downrange at ~580 µs after impact. Wind speeds calculated from the mobilized dust are ~150 m/s. 2b) Dust mobilized back toward the crater by reverse winds at 1000 µs after impact. Calculated wind speeds are ~30 m/s.