EFFECT OF AN ATMOSPHERE ON THE EXPANSION AND SETTLEMENT OF AN IMPACT EJECTA PLUME.

Megan L. Harwell[1] and Henry J. Melosh[1]. [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, USA

Introduction: Immediately following an impact, material is excavated from the growing crater and spewed into the region around it, forming a plume that settles into the ejecta blanket. About half of the material in the ejecta blanket falls within one crater radius of the rim of the crater [1]. The expansion of the ejecta plume in a vacuum has been well studied [2] in research that established relationships between the excavated debris' speed and the radius at which it leaves the crater. However, many planetary craters grow in the presence of at least a thin atmosphere. As the ejecta plume expands into an atmosphere, the particle trajectories interact with the atmospheric gases and deviate from ballistic paths as they lose both energy and momentum. In this work, we model the expansion and settlement of an ejecta plume taking the atmosphere into account. Previous research [3,4] has modeled this interaction, both analytically and in small-scale experiments, but we have applied a novel numerical model to this problem that is capable of extending this work to larger scales.

Methods: We adapted the two-fluid hydrocode, KFIX, originally written at Los Alamos National Lab [5], to model ejecta expansion into the Martian atmosphere. This 2D axially symmetric code couples two fluids (or a fluid and a particulate solid), accounting for the exchange of momentum and energy between the two fields as the constituents collide and interact. The impactor and target material are modeled as a particulate solid of basaltic density, with an atmospheric gas (treated as an ideal gas) given the molecular weight of carbon dioxide. Prior to material injection into the mesh, the atmosphere is equilibrated with a pressure, temperature, and density gradient comparable to that near the surface of Mars. Free slip boundaries border the computational mesh, preventing material from leaking out of the computational area. The ejected debris is introduced in the lower left boundary of the mesh from a crater 4 km in diameter (2 km in radius in Figs. 1 and 2).

The simulated crater excavation follows the established relationship [2] between the material's radius from the point of impact and the speed at which it is ejected. The solid is assigned an initial angle of 45° and, in the current simulation, modeled as a mass of uniform-sized spheres 1 cm in diameter. The lower left boundary of the mesh is partitioned into ten injection cells, with the bounds of the active cells shifting from the point of impact towards the transient crater rim as more material is injected into the computational region. The tempo of this shift is determined from a relationship between time elapsed since the impact and the radius of the active cells [2]. The cell transition from inactive to active back to inactive occurs smoothly, with the cells nearer to the point of impact active for less time than the outer cells. This design ensures that the mass injected into the computational area follows the established relationship between excavated mass and radius, following Maxwell's Z-model [6]. Very little material is ejected at high speed from close to the impact point, whereas the mass of ejecta increases monotonically toward the rim of the transient crater. The total mass ejected agrees with standard Z-model scaling relations.

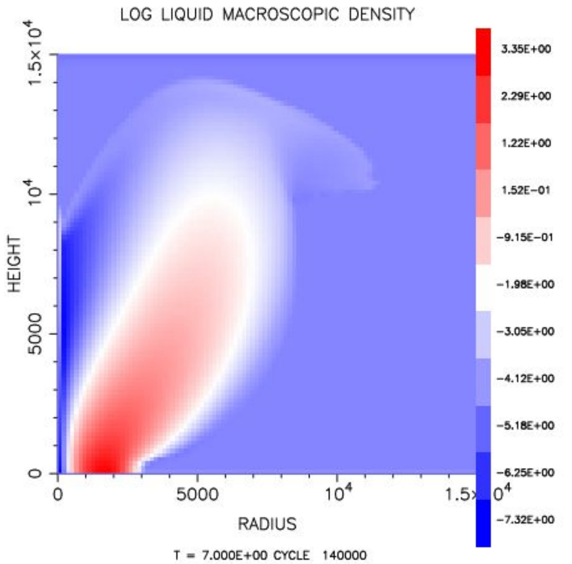

Figure 1: Logarithm of the density of the ejecta 7 seconds after impact. Injection cells nearest the point of impact have already become inactive. The red regions have the highest density of ejecta while blue has the lowest.

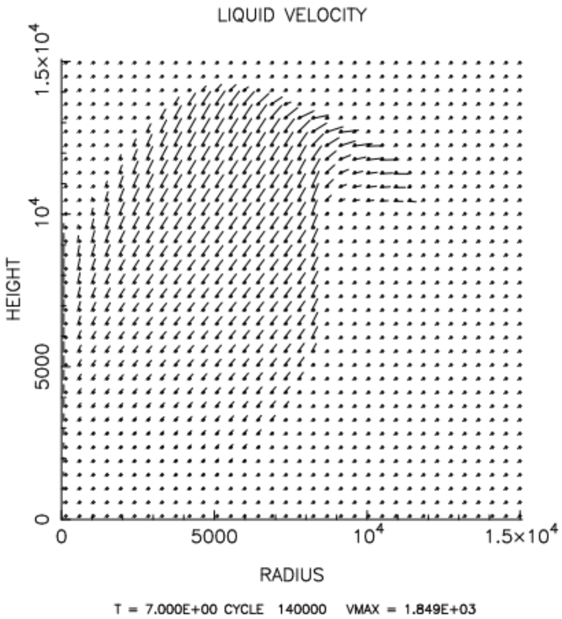

Figure 2: A vector plot of the ejecta velocity following the impact by 7 seconds. The ejecta in the region cocooned by the outer boundary retain their original orientation of 45º, unlike the material near the edges.

Results: Figure 1 shows the macroscopic density of the solid ejecta near and above the actively injecting cells and is surrounded by a material of considerably lower liquid density. This lighter blue region loosely borders the bulk of the ejecta material and represents the fraction of liquid in the primarily gas cells. Figure 2 shows the speed of the ejecta material as a vector plot. The material farthest from the origin has been most affected by the atmosphere, shown by the deviation from the initial angle. Around the edges of the ejecta velocity field, the vertical component of velocity becomes dominant as the ejecta expands upward into the lower density atmosphere above one scale height. This demonstrates that the ejecta's path deviates markedly from a ballistic trajectory. Furthermore, the ejecta as a whole move much faster and farther than an individual 1 cm diameter basalt fragment would travel from its injection location, exhibiting the collective effect of the mass of ejecta. At the same time, the model properly accounts for the ability of the atmosphere to interpenetrate the ejecta cloud while at the same time exchanging momentum and energy with the ejecta.

Discussion: As the ejecta plume expands, the ejecta that meets the atmospheric gas lose components of their velocity to the surrounding atmosphere. As this happens, the fast, early-ejected material partially shields the following ejecta from interacting with the atmosphere. This allows the later ejecta to expand in its original direction, then settle, forming a deposit surrounding the crater. The dominance of the vertical component of velocity of at least the outer solid ejecta suggests that the ejecta blanket may have become concentrated nearer to the rim than a purely ballistic model would predicts. This computational result agrees qualitatively, at least, with small-scale laboratory experiments [7].

In future work we plan to vary the ejecta particle size with ejection location as well as including a shock wave simulating the entry of the projectile that created the crater. Additionally, the computational will run on a larger mesh to prevent potential interaction between the ejecta material and the boundaries. Preliminary work on the shock wave indicates that the ejecta expand faster than the air shock and thus little interaction occurs except near the axis of symmetry.

References: [1] Melosh, H. J. (1989), *Impact Cratering*. [2] Richardson, J. E. et al. (2007), *Icarus* 191, 176-209. [3] Schultz, P. and Gault, D.E. (1979), *JGR* 84, 7669-7687. [4] Barnouin-Jha, O. and Schultz, P. (1996), *JGR* 101, 21,099-21,115. [5] Rivard, W.C. and Torrey, M. D. (1976), LA-NUREG-6623. [6] Maxwell, D.E (1977). *Impact and Explosion Cratering*, 1003-1008. [7] Schultz, P. (1992) *JGR* 97, 11,623-11,662; Barnouin-Jha, O. and Schultz, P. (1998) *JGR* 103, 25,739-25,756.

Acknowledgements: This research was funded in part by the Gianni Ascarelli Student Award given by the Purdue University Department of Physics and Astronomy.