**NEW MODELS OF ATMOSPHERIC EFFECTS ON EJECTA CURTAIN FORMATION.** M. A. Carlson[1], M. L. Harwell[2] and H. J. Melosh[3], [1]Purdue University Physics Dept. Carls113@purdue.edu, [2]Los Alamos National Lab, [3]Purdue University EAPS Dept.

**Introduction:** During the excavation stage of crater formation, the material excavated from an impact crater forms an ejecta plume. Under vacuum, this material follows a ballistic trajectory in which the leading edge forms an ejecta curtain [1]. The expansion of the ejecta plume under vacuum has been well studied and relationships between the excavated debris' speed and the radius at which it leaves the crater have been developed [2]. However, within even the most tenuous atmosphere the ejecta interacts with the atmospheric gases and deviates from its ballistic path as it loses both energy and momentum. Previous numerical studies on the shape of ejecta curtains have relied on using a simple drag coefficient to model curtain formations in given atmospheric conditions [3,4]. However, such an approach may not account for the energy and momentum transfer from the particulates to the surrounding atmosphere. Through altering the characteristics of both the ejecta and the atmosphere, we can observe patterns in ejecta curtain simulations under different conditions. Our work aims to demonstrate the effects of varying particulate sizes and atmospheric pressures (such as those on Earth and Mars) on the formation of ejecta curtains.

**Methods:** KFIX, an Eulerian hydrocode developed at Los Alamos National Lab in the 1970s, is capable of modeling dual-material and dual-phase flows [5]. By modeling both the ejecta material and the atmosphere as linked, continuum fluids rather than individual particles, we can effectively capture the interactions between the ejecta and the atmosphere while conserving energy and momentum. If one chooses the first phase to be the atmosphere and the other to be the particulates ejected from the crater, the exchanges of energy and momentum between the ejecta curtain and the atmosphere can be accurately modeled by KFIX [6], given suitable equations of state for the gas (we assume an ideal gas with an appropriate mean molecular weight) and solid (we use a stiffened gas equation of state [7] for basalt).

Prior to the first computational time step, the atmosphere is pre-stressed to create a pressure, temperature, and density gradient in the mesh comparable to that near the surface of Mars or the Earth. The impact axis and plane are free slip boundaries, preventing the loss of material from the computational area through the ground. The top and far right edges are outflow boundaries, allowing material to leave the computational area and not rebound. The ejected debris is introduced in the lower left boundary of the mesh through an inflow boundary to form a crater 400 m in diameter.

The excavation flow of ejecta follows the established relationship between the material's radius from the point of impact and the speed at which it is ejected [2]. The material is ejected with an initial angle of 45° and modeled as uniform spheres of various diameters, as shown in the plot legend. The inflow boundary at the lower left of the computational region is partitioned into ten areas of ejecta injection. The flow of this material into the computational region, or atmosphere, is determined by the duration of crater formation in the simulation. As the crater is excavated, the bounds of active inflow cells shift from the center of the crater to the diameter of the transient crater rim at a rate determined by the amount of material excavated and Z-model predictions [2,8]. 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 relationship between excavated mass and radius established in Maxwell's Z-model [8]. Material close the impact point is ejected at high speed and as the ejecta curtain moves towards the transient crater rim, the ejecta velocity decreases. The mass injected per unit time stays constant through excavation, but the mass injected per unit radius increases as the ejecta curtain approaches the rim of the transient crater. In this way, we ensure that the simulated ejecta plume's behavior is physically consistent with accepted models.

KFIX accepts a variety of input parameters to modify the event modeled. Those most relevant to ejecta curtain studies include fluid pressure and density, gravity, particulate size, crater size, and temperature. Through these parameters, we can accurately model crater excavation in a variety of atmospheric environments, including Earth and Mars.

**Results:** On both Mars and the Earth, very large ejecta particles (1 cm on Mars; 1 m on Earth) are mostly unaffected by the atmosphere and their plumes closely resemble impact ejecta curtains in a vacuum. Small particles, however, are strongly affected by the atmosphere, which both holds them back from expanding to large radii and entrains them in rising convective plumes of hot gas. Such particles may not be deposited at all far beyond the crater rim, seeming to rain out inside the crater itself or just outside the final rim.

The general rules of how these parameters affect the formation of ejecta plumes under atmospheric conditions are somewhat intuitive:

1. Less dense atmosphere does not affect the ballistic trajectory of the ejecta, thus the curtain is unchanged
2. Smaller particle sizes lead to a more noticeable change in the ejecta trajectories

However, it is unknown exactly how much of an effect each rule has on the ejecta curtain.

The following graph (fig 1) shows a simulation run for an impact on Mars with 1 cm particles. The black circles are tracers that show the average progression of the ejecta curtain. The contour plot behind the tracers is the macroscopic liquid density showing the actual ejecta cloud excavated by the impact.

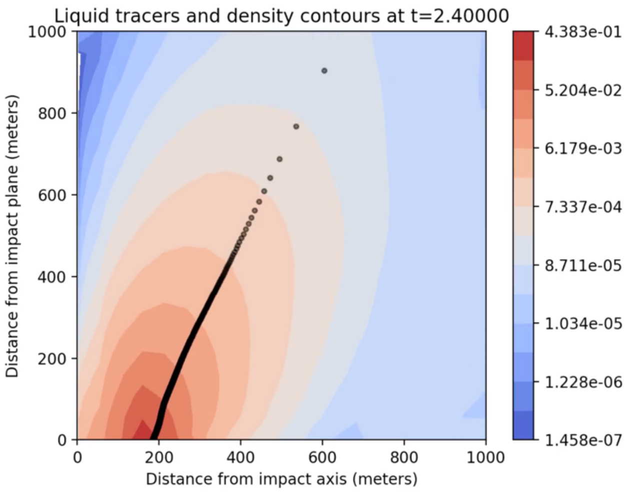


*Figure 1 Ejecta curtain basalt tracers and density contours.*

The following two graphs (figs 2, 3) show the time evolution of the ejecta curtain tracers for different parameters. It's easy to see the two rules stated earlier in effect with the momentum transfer from the ejecta curtain to the surrounding atmosphere stopping the curtain prematurely.

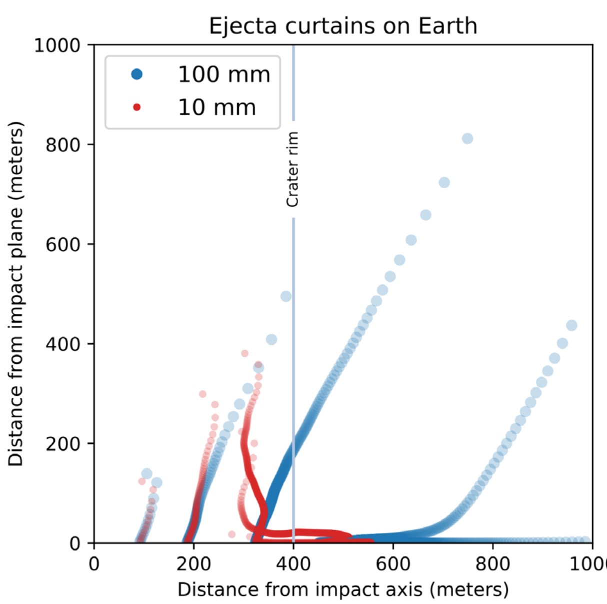


*Figure 2 Ejecta curtains at different times on Earth for different particle sizes.*

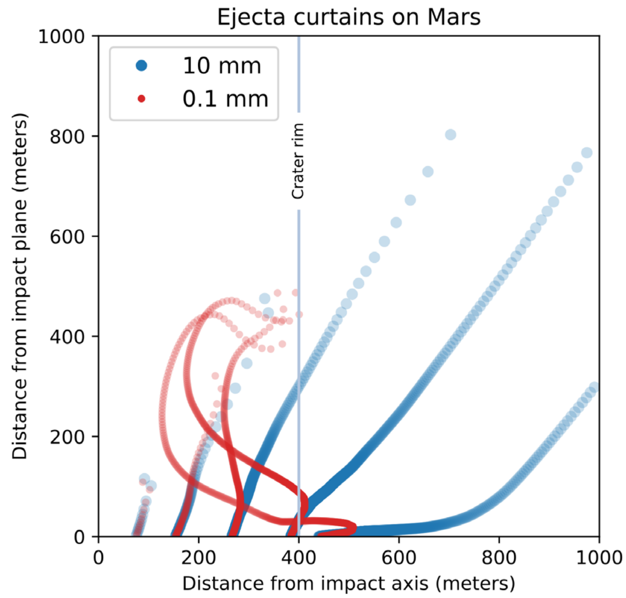


*Figure 3 Ejecta curtains at different times on Mars for different particle sizes.*

**Conclusions:** As seen in the graphs, the atmosphere plays a significant role in the trajectory of smaller particles, whereas it has only minor effects on larger particles. Quantifying this effect to the degree of accuracy desired requires applying additional constraints and dynamics not currently included in the simulation, which are detailed in the following list.

1. Implement a particle size distribution instead of using a single, fixed radius
2. Study the effects of an initial bow shock from the projectile
3. Increase the area simulated to decrease any boundary effects

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