Modeling Impact Cratering on Phobos.

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Introduction: We model the process of mega-cratering on the Martian moon Phobos, employing the meshless method Adaptive Smoothed Particle Hydrodynamics (ASPH). Specifically we consider scenarios that could form the well-studied Stickney crater without disrupting Phobos. We are interested in this problem both to advance our understanding of the formation of mega-craters on small bodies and as a validation test of our modeling methodologies.

Background: Phobos is a small Martian moon (roughly $27 \times 22 \times 18$ km) with a low density ($\sim$ 1.95 g/cc). It possesses a massive distinctive crater, Stickney, which with a diameter of roughly 10 km is of order Phobos' effective radius. Prior models of the formation of Stickney performed by Asphaug & Melosh [1] have been completed employing two-dimensional SALE techniques. The authors modeled a spherical Phobos consisting of either solid rock or ice, using established scaling laws [4] to choose the relevant parameters of the impactor (size and velocity). They were able to study the early time effects of the impact (on the order of a few seconds), and estimate the crater properties based on the fracture and velocity distributions in the post-impact Phobos up to this time.

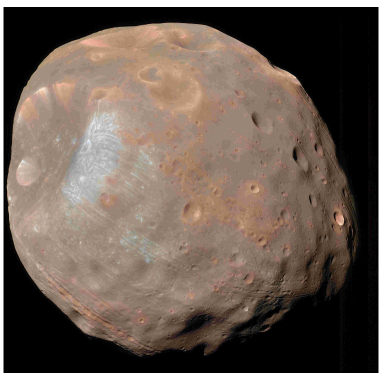
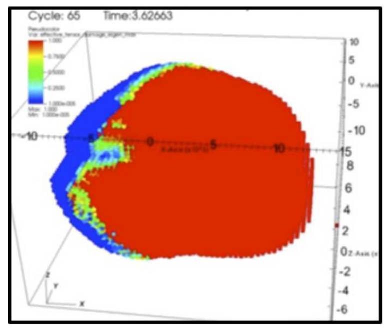
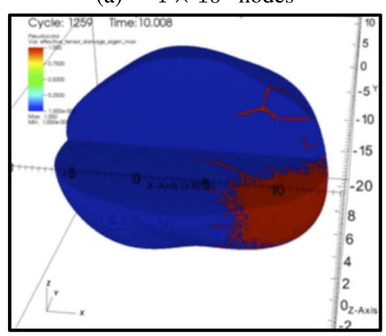


Figure 1: Phobos, with Stickney on upper left.
Imaged by the HiRISE: Moon of Mars Credit: NASA/JPL/University of Arizona.

Simulations: For our study we employ an ASPH methodology ([3], discussed in a separate abstract) which has been extended to include treatments of solids with strength, models for micro-porosity, and material damage models to handle failure and fracture. We perform a suite of simulations using traditional impact parameters (basalt Phobos, 6 km/s impactor) at different resolutions to study the effects on the resulting crater properties as well as the bulk changes in Phobos. Since this is a three-dimensional study we initialize the shape of Phobos based on the spherical harmonic fit provided in [6]. The composition of the moon is also varied, from a solid monolith to a porous body. The porous material offers another route for damping and absorbing the impact energy through pore collapse. In analyzing the interplay between deposited energy and the resulting crater size, we vary the impactor size and velocity in accordance with previously used scaling laws. We then deviate and explore new parameters (still obeying the scaling relations of [4]) as we find the traditional impact parameters result in unprecedentedly low crater yields. We find that some parameters we consider do not have a significant effect on the impact results, such as the impact angle and the addition of a layer of strengthless regolith.



(a) $\sim 4 \times 10^4$ nodes



(b) $\sim 2 \times 10^7$ nodes

Figure 2: Post-impact Phobos cutaway of the same impact (6 km/sec) performed at different resolutions. The damage is significantly reduced in the high-resolution case (b).

Results: Similar to Asphaug and Melosh, we assess our impact results by measuring the fraction of Phobos damaged (by volume or mass) and the velocity distribution of material to estimate crater excavation. Our study of resolution showed a drastic decrease in the damage of Phobos with increasing resolution (Fig. 2), an effect shown to stabilize at high enough resolutions. This effect is due to the way damage is treated in the formalism of Grady and Kipp [2]. For this early-time evolution we find that using the more realistic shape of Phobos did not greatly influence the result. However, the gravitational environment

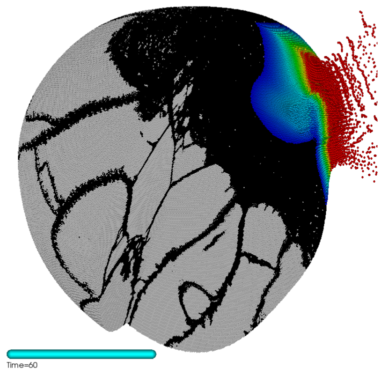
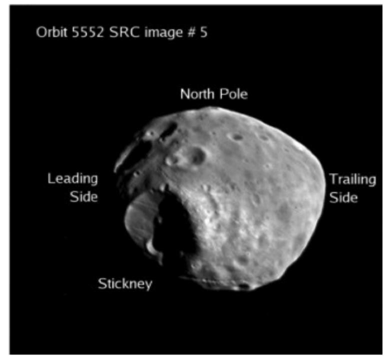


Figure 3: Cutaway view of the damage (grey-scale) and velocity (color-scale) for a 222 m radius, 8 km/sec impactor 60 seconds after impact. The red material will escape Phobos entirely, while the blue to yellow material will be redistributed outside the crater volume.

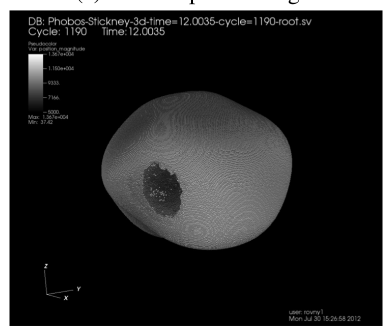
of the moon and the correspondingly varying escape velocities due to Phobos' non-spherical geometry may have some influence on the late-time evolution of the material thrown up by the cratering event [6].

The introduction of porous material causes a two-fold effect: the damage is more strongly localized to the region of impact, and energy is absorbed in the compression of the pores. Both of these effects (combined with the newly recognized resolution dependence of the damage) contribute to the possibility for larger craters to be formed on relatively small astronomical bodies without suffering catastrophic disruption. We find in all cases that Phobos is heavily fractured following an impact such as the Stickney event, with fractures propagating out from the impact site throughout the body (see Fig. 3). Models such as this can help in understanding the process of fracturing small solar system bodies and ultimately forming rubble pile objects.

In the future this work will be extended to better understand crater formation by running simulations to later times when the hydrodynamic physics of shocks, sound-waves, and damage are not relevant (and can therefore be neglected in choosing the time step), but rather gravitation, friction, and inertia dominate. In this way we can directly model the final distribution of the material and crater shape, rather than inferring these quantities based on the interim velocity distribution of the material such as seen in Figs. 3 & 4.



(a) Mars Explorer image.



(b) Simulated crater.

Figure 4: (a) Mars Express image (Credit: NASA/JPL/University of Arizona) of Stickney vs. (b) simulated result. Note: the damaged nodes that meet the criteria for escaping Stickney have simply been removed for this image – this is not yet a true crater shape.

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