

MODELING THE BALLISTIC BEHAVIOR OF SOLID EJECTA FROM THE DEEP IMPACT CRATERING EVENT. J. E. Richardson¹ and H. J. Melosh², ¹Center for Radiophysics and Space Research, 310 Space Sciences Building, Cornell University, Ithaca, NY 14853, richardson@astro.cornell.edu; ²Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721. jmelosh@lpl.arizona.edu.

Introduction: On July 4, 2005, the Deep Impact mission successfully collided a 370 kg impactor with the surface of Comet Tempel 1, at a closing speed of 10.2 km/sec and oblique angle of about 60° from the surface normal. This impact produced a cratering event which was observed by a flyby spacecraft in two time windows: from 0 to 800 seconds after the impact (approach), and from 45 to 75 minutes after the impact (look-back). The resulting solid ejecta plume, highly visible due to its extremely small particle distribution, displayed classic gravity-dominated cratering behavior during its ejection and observed fallback phases: forming an inverted, conical cloud of launched particles which remained attached to the comet's surface and slowly expanded over the course of the observations. During the first 800 seconds following the impact, the interior of this ejecta cone was observed as the flyby spacecraft approached the comet, while during the look-back phase of observations, the exterior of this ejecta cone was observed. These later images permit measurements of the ejecta cone's expansion over a time span of nearly half an hour, and thus provide a quantitative means for estimating the strength of Tempel 1's gravity field, in which these ejecta particles were ballistically traveling and "falling." This gravity measurement also permits an estimate of the comet's mass and bulk density given a reasonable shape model for Tempel 1 [1]. These estimates are made using a first-order, three-dimensional, forward model of the impact's solid ejecta particle behavior, described below.

Basic Model Description: Our numerical ejecta plume model is primarily based upon the impact ejecta scaling laws described by Housen, Schmidt, and Holsapple [2], modified slightly to more properly simulate very late-stage ejection velocities and the ejection angle variations (ejecta plume shape changes) shown in impact cratering experiments [3]. Transient crater size is computed from the Pi-group scaling laws, with a target strength parameter added to allow the simulation of strength-dominated cratering events in addition to the more familiar gravity-dominated cratering events [4]. These analytical results are applied in a dynamical simulation which models – via tracer particles – the ejecta plume behavior, ejecta blanket placement, and impact crater area resulting from a specified impact on an irregularly shaped target body, which is rendered in three-dimensional polygon fashion. The target model can be placed in a simple rotation state about one of its principal axes, with the impact site, projectile and target parameters specified by the user. The gravitational force from the irregular target body

(on each tracer particle) is determined using the polygonized surface (polyhedron) gravity technique developed by Werner [5].

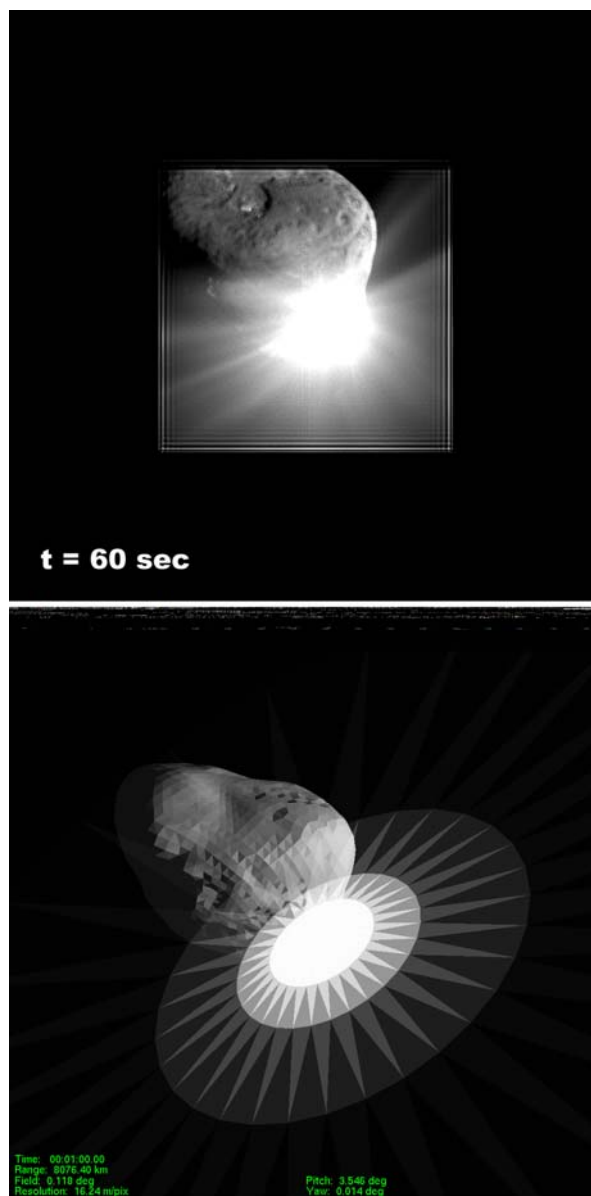


Figure 1: (top) Deep Impact High Resolution Imager (HRI) frame 9000936.001, showing the solid impact ejecta plume one minute after the impact. In this view we are looking at the interior of an inverted cone composed of fine ejecta particles, which is rapidly expanding both radially and axially with regard to the surface normal at the impact site. Several prominent rays are also visible in the plume. (bottom) A numerical simulation of the impact ejecta plume, shown at the same time and from the same viewpoint as the

above image. Plume opacity is computed from a particle size distribution ranging from 0.01-100 microns in diameter.

Modeling Ejecta Plume Detail: To more realistically simulate the physical properties of an ejecta curtain and eventual blanket resulting from an impact, we model the ejecta curtain as a three-dimensional polygon object by linking a network of individual tracer particles to form triangular polygons. In this form, the optical depth and opacity of each polygon in the ejecta curtain is calculated at each time step, and rendered appropriately (assuming a user specified particle distribution). Individual polygon mass-load estimates are derived from the Maxwell Z-model of impact excavation flow [4], while the particle size distribution were determined empirically by Lisse, et al. [6]. A detailed discussion of this model is contained in [7].

Discussion: Although the ejecta plume from the impact produced by this mission shows several features indicative of an oblique impact, such as a prominent up-range gap during the early stages of excavation flow, it's overall (first-order) behavior can be modeled quite well using the ejecta behavior scaling laws derived from normal-incidence impacts into loose, low-strength, target materials [2]. The fact that the solid ejecta plume remains visibly attached to the comet's surface (within viewing geometry limitations) is indicative of an extremely weak target (<65 Pa shear strength) and a gravity-dominated cratering event. Initial particle ejection angles appear to be quite low over the first ~1/5 of crater growth, perhaps indicative of a deep impactor penetration depth (a few tens of meters) into a volatile-rich target, but rapidly increase and follow more canonical behavior thereafter. The expansion of the solid ejecta cone (plume) in the look-back images is best modeled using a weak surface gravity field of 30 +/- 20 mgal, which implies a comet bulk density of 400 +/- 300 kg/m³ (revised values to be supplied at the time of presentation). The base of the ejecta cone also shows evidence of anti-solar motion due to solar radiation pressure (a few hundred meters), which is consistent with ejecta particle sizes on the order of a micron in diameter.

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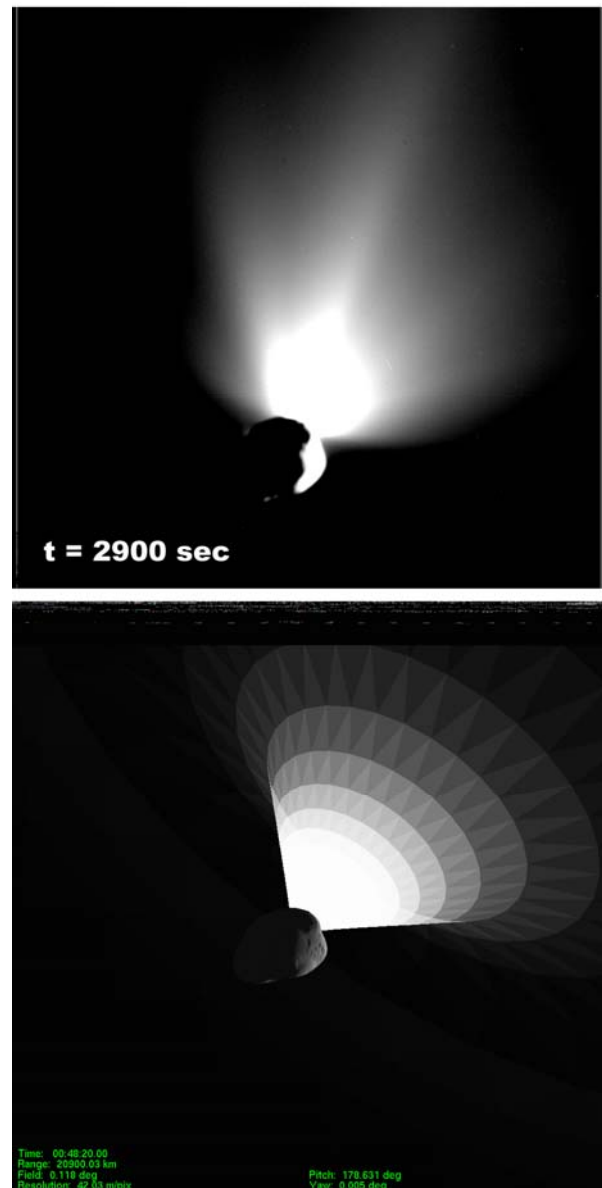


Figure 2: (top) Deep Impact HRI frame 9010003.001, showing the solid impact ejecta plume 48 minutes after the impact. In this view we are looking at the exterior of an inverted cone composed of fine ejecta particles, which continues to expand as particles near its base fall back on to the comet's surface. (bottom) A numerical simulation of the impact ejecta plume, shown at the same time and from the same viewpoint as the above image. The plume expansion rate is a sensitive function of the comet's gravity field.