
We have used the CTH Eulerian shock physics code to study 2-D and 3-D representations of the penetration of Shoemaker-Levy 9 fragments into the Jovian atmosphere and the resulting fireball growth and fallback. We are hopeful that simulations such as this will eventually provide information as to the size, mass and composition of the impacting fragments. Of particular importance, however, is obtaining unique values for at least some of these properties. We have discovered that growth of the fireball during the first few minutes primarily depends on energy deposited at relatively high altitude in the Jovian troposphere and stratosphere. Energy deposited below this level (by large, dense impactors, for example) has relatively little influence on early-time fireball growth. At high altitude in the Jovian atmosphere, energy deposition is primarily a function of the cross-sectional area of the impactor; therefore, energy deposited by a 3-km diameter cloud of icy debris is about the same as that due to a 3-km sphere of solid ice. Regarding the early-time growth of the fireball, then, the proper question to ask is: “What is the effective size of the fragments (or swarm of debris) at the time of impact?” Based on observed plume heights and trajectories, we estimate that the largest fragments of S-L 9 had effective diameters between 2 and 3 km in diameter at the time of impact.

We used CTH [1] to study 2-D, axisymmetric representations of the penetration portion of each impact event and 3-D, bilaterally symmetric simulations of the resulting fireball growth and fallback. The cometary fragments are assumed to consist of spherical, strengthless water ice impacting a gravitationally stable hydrogen/helium atmosphere scaled to account for the 45 degree incidence angle. The penetration calculations are performed in a reverse-ballistic sense (the atmosphere impinges at 60 km/s on the initially stationary cometary fragment) in order to reduce numerical diffusion in the region where most of the action happens (i.e., the small region enclosing the fragment). The results from the penetration simulations are inclined at 45 degrees and mapped into a 3-D computational mesh as the starting conditions for studies of fireball growth and evolution.

To demonstrate the influence of fragment mass and size, penetration simulations were performed with 1-, 2- and 3-km fully dense and porous ice fragments. Details of these calculations are described elsewhere [2-5]. Fig. 1 shows the energy deposited by each fragment as it penetrated the Jovian atmosphere. Note the similar energy deposition curves at high altitudes for the 3-km fully-dense (0.95 g/cc) and porous impactors (0.3 g/cc). The left half of Fig. 2 shows a 2-D simulation of the fireball that results from the impact of a fully-dense 3-km ice sphere. The right half of Fig. 2 shows the resulting fireball if the lower portion of the energy deposition (below -50 km altitude) is removed. The similarity of the two fireballs suggests that early-time fireball growth is primarily dependent on high altitude energy deposition (for large, dense fragments, this is a small fraction of the total energy deposited). Following the discussion of Fig. 1, we conclude that fireball growth in the first few minutes depends primarily on fragment size, not density. We have extended our fireball simulations to twenty minutes long enough to observe the fallback of plume material onto the Jovian stratosphere (Fig. 3). The calculated diameter of the fallback region produced by a 3-km impactor is about 30% larger than the dimensions of the G impact site. This suggests that the G fragment had an effective diameter between 2 and 3 km. Future calculations will take a detailed look at the morphology and thermal signature of the fallback region.

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**Fig. 1.** Comparison of four penetration simulations showing fragment size/mass dependence. Projectiles consist of 1-, 2- and 3-km fully-dense, strengthless, ice spheres and a porous 3-km ice sphere (mass equivalent to a 2-km fully dense ice sphere) [2].

**Fig. 2.** Comparison of 2-D fireball simulations demonstrating that early-time fireball growth is dominated by high altitude energy deposition. The fireball on the left results from energy deposited by a fully dense 3-km ice sphere. That on the right from energy deposited at high altitude (above ~50 km) only.

**Fig. 3.** Three-dimensional simulation of the first 20 minutes of plume evolution after the impact of a 3-km fragment on Jupiter. The shade of the simulation plots is keyed to log(density) with the black-to-gray density cutoff occurring at $10^{-12}$ g/cm$^3$. The timing of the last four frames corresponds roughly to the times of HST images of the fragment G impact[6]. Note that most of the fireball mass is ejected from right to left, back in the direction from which the impactor came.