LARGE SCALE IMPACT ON THE EARTH WITH AN ATMOSPHERE,
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Large scale impacts are considered to be an important phenomenon bearing on accretion and evolution of the terrestrial planets and their atmospheres. It has been suggested that large impacts may have played a critical role in the evolution of life (5, 6). We need to understand the interaction of the impactor with the atmosphere and the solid planet and the impact ejecta with the atmosphere.

The flow field due to the passage of an 10 km diameter bolide through the atmosphere without the effects of impacting the planet surface was calculated by Roddy et al (6). The flow fields induced by impacting a planet without an atmosphere has been previously calculated (6-11). Atmospheric flow fields due to either passage of a bolide through the atmosphere or surface energy release were studied by Jones and Kodis (12). Previously we calculated (9, 10) the flow fields from an impact with a uniform density and finite thickness atmosphere and Schultz and Gault (13) performed laboratory scale experiments under similar conditions. We now address, for the first time, the energetics and flow fields from an impact onto the Earth with an exponential atmosphere.

Numerical simulations of this problem are difficult because of the contrast in the density of an atmosphere, versus, the bolide. We considered the bolide as being initially incompressible and modeled both the wake from a Mach 58, 20 km/sec, impactor with a < 1° sheath traveling at 5.1 km/sec. We also calculated the presence of a 8 x10^11 Kg jet of 40 km/sec radially expanding gas, from the gas that was trapped in front of the bolide prior to the time of contact with the surface (see Figure 1). The shock in front of the bolide reflected from the planetary surface and reverberates between the two. The impact of the bolide with the surface drives a strong conical shock normal to the planetary surface and continues to drive it radially outward as the bolide penetrates the surface. We used a two-dimensional mixed Lagrangian-Eulerian numerical algorithm (16) to calculate the flow after bolide impact with the Earth. The radially expanding trapped gasses drive a strong hemi-spherical shock away from the impact site (see Figure 2). This shock propagates well away from the impact site before the surface rock ejecta plume starts to evolve and thus very high velocity initial flow would not entrain ejecta particles. The evacuated region in the atmosphere is filled in by gasses that are moving radially inward and downward toward the surface at comparable rates. The downward moving column of gas around the projectile stagnates at the planetary surface and results in a strong shock diffracting back up and around the projectile. When this shock reaches the evacuated region it accelerates an annular region of gas upward that collides with the downward moving regions from the upper atmosphere. This produces a region of very hot gas as observed, above the impact site in the experiments of Schultz and Gault (13). Eventually all of the downward moving gas is stagnated and turned upward and it first forms a column of gas moving upwards (see Figure 3). Eventually this column flow pattern evolves into a nearly hemi-spherical shape (see Figure 4). The shock front that moves away from the impact site is driven by the initial transfer of energy to the atmosphere via the wake and jet. In agreement with our previous calculation for a constant density atmosphere (9, 10) the work done by the Earth ejecta plume on the atmosphere is a small contribution to the atmospheric energy budget although it would be important on a longer time scale. The fraction of the 10 km diameter 20 km/sec bolide energy promptly transferred to the atmosphere is ~ 6% which compares to a ~ 5% for 5 km/sec impact onto a constant density atmosphere (10). The present model will permit improvements to present approximate models (14, 15) for atmospheric loss due to impact.
Fig. 1. Initial conditions for start of numerical simulation. Atmospheric flow conditions were analytically calculated. Impact velocity is 20 km/s for silicate, 2.7 g/cm³. Impact of radius 5 km. Target is silicate.

Fig. 2. Flow field at dimensionless time 0.9. Arrow on left hand side show particle velocity. Dots on left indicate position of marker particles. Lines on right hand side indicate path of marker particles.

Fig. 3. Flow field at dimensionless time 3.32.

Fig. 4. Flow field at dimensionless time 13.4.