LARGE SCALE OBLIQUE IMPACTS ON THE EARTH ; John D. O'Keefe and Thomas J. Ahrens, Seismological Laboratory 252-21, California Institute of Technology, Pasadena CA 91125

The impact of large bodies is an important factor in the accretion of the terrestrial planets, the genesis of their atmospheres[1234], and possibly the evolution and extinction of life. The phenomena associated with impact of large bodies on the earth with its attendant atmosphere has been numerically simulated[5 6] and measured in small scale laboratory experiments[7]. These studies were of impacts normal to the earth's surface. Here we address the more probable cases where the impact angles are oblique.

We have calculated the flow fields for normal and oblique impacts using a two-dimensional numerical computational algorithm[8]. This two-dimensional algorithm accurately models the flow field for normal angle impacts because the flow field has axial symmetry. In the case of normal impacts, the pressure and density are approximately constant across the front of the bolide, while at impact angles less than 90 °, the pressure and temperature vary exponentially with the atmospheric scale height. As for normal impacts, the shock wave in front of the bolide encounters the planet surface and reverberates between the bolide and the planet until the bolide strikes the surface and drives a radial conical shock which results in a 40 km/s radial jet of atmospheric gas emanating from the impact zone.

In the case of oblique impacts, the algorithm is an approximation to the three-dimensional flow field, most accurate in the plane normal to the planet's surface which contains the impactor trajectory. We previously used this technique to calculate the impact angles and velocities required for significant jetting and entrainment of planetary material[9].

Both the atmosphere and the planetary surface are included in the model. The atmosphere was assumed to have a scale height of 7 km. The impactor diameter is 10 km and its velocity is 20 km/s. The flow fields were calculated for impact angles ranging from 90°(normal) to 25° to the planetary surface. The flow-field resulting from passage of the impactor through the atmosphere was analytically calculated and used as the initial conditions for the numerical simulations[5]. We assumed that the bolide was incompressible during the passage through the atmosphere (Fig. 1).

The wake field behind this Mach 58 bolide was found to have a < 1° sheath travelling at 5 km/s. The front surface of the bolide was slightly flattened in a plane normal to the trajectory. A bolide with a diameter greater than the scale height, the atmosphere it encounters is trapped in front of it prior to impact. In the case of fairly oblique impacts (angles < 45°), there is not a significant amount of shock interaction prior to impact with the planetary surface and the amount of atmospheric jetting is reduced. In addition to jetting of the trapped atmosphere, there is jetting of the bolide and planet. O'Keefe and Ahrens[2] showed that at 20 km/s obvious jetting of planetary and bolide material occurs for impact angles in the range of 60 to 15°.

Preliminary flow fields for an impact angle of 25° are shown in Figs. 1 through 3. At this angle there is little jetting of the atmosphere prior to impact with the surface and most of the atmosphere is trapped in front of the bolide. The air shock pressures prior to impact in front vary from 6.9 kbars at the surface to 1.9 kbars at top of the face. As the bolide penetrates the planetary surface, the air shock is reflected from the planetary surface in front of the bolide. Subsequently, because of the interaction of the bolide and the planet, a strong jet of vaporized material followed by melt and solid material is produced. The jet and following materials propagate parallel to the planetary surface and the vapor drives a strong shock in the atmosphere (see Fig. 3). The oblique impact case differs from the normal case in that the ejecta is propelled into a quiescent atmosphere, whereas in the latter the ejecta is propelled after reflections of the atmospheric shock waves create a radial flow field that is parallel to the ejecta trajectories[5]. Because the forward jet is parallel to the planetary surface it transfers energy more effectively to the dense part of the atmosphere than normal impacts. The relative greater efficiency of oblique impact in providing sufficient energy for atmospheric escape will be discussed in detail in future work.

Oblique impacts

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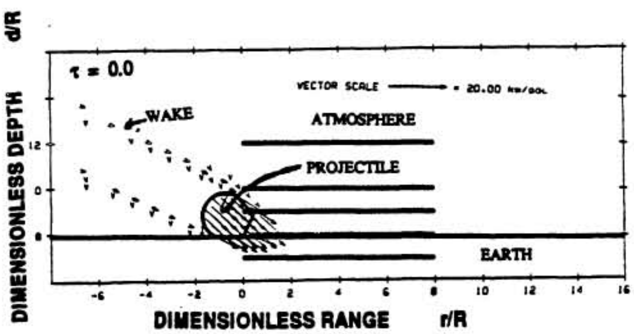

Figure 1 The atmospheric flow field at the time the impactor just hits the Earths surface.This is the initial condition for the numerical simulation shown in figures 2 and 3 The impact velocity is 20 km/s and the impact angle is 25°. The impactor radius , R , is 5 km. The horizontal line of dots in the atmosphere and earth are markers which show displacement in the subsequent flow.

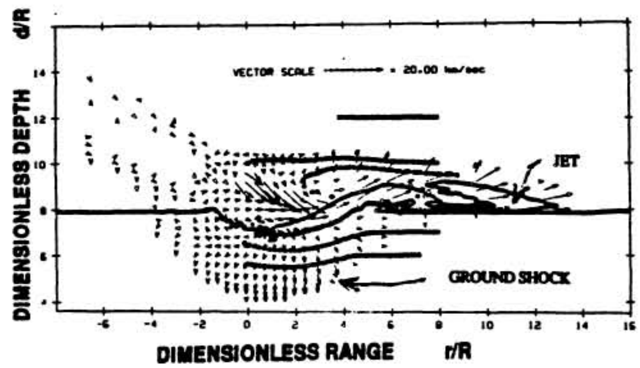

Figure 2 Flow field at dimensionless time = 6.5 (impactor diameter divided by velocity)

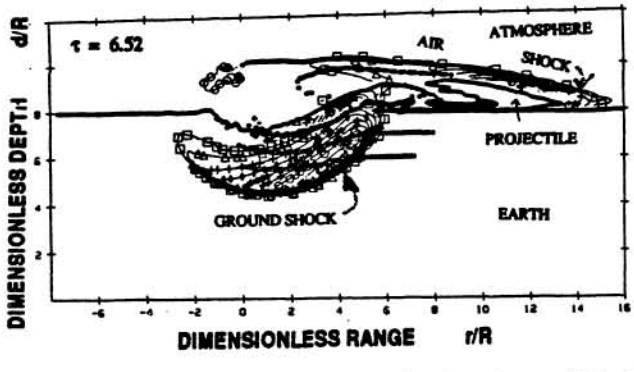

Figure 3 Pressure contours at dimensionless time = 6.5. Peak pressure in earth, projectile, and air is 137, 25, and 0.1 GPa, respectively. Contours indicate 0.005, 5, 10, 20, 30, 40, 50, 60, 75, and 90 percent of peak value.

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