
In the study of the ejecta transport from impact crater, one of the usual assumptions is that the ejecta particles are non-interacting. Whether the ejecta particles are non-interacting or not, the trajectories of these particles play an important role. The trajectories of ejecta particles depend on (i) the initial velocity vector of the particles, (ii) the gravitational acceleration of the planet on which we study the ejecta transport and (iii) the aerodynamic forces on the ejecta particles due to the atmosphere through which the particles move. In most of the studies of the trajectories of the ejecta particles only the drag force is considered. This is a first attempt to show the effect of the lift on the trajectories of the ejecta particles. As we shall show later, there are many different kinds of trajectories of the ejecta particles if we include both the lift and the drag forces on the particles and these trajectories may differ greatly from those without lift.

There are two cases where the lift force will occur on the ejecta particles:

(i) If the shape of the ejecta is elongated, the lift force will occur when the body moves at an angle of attack with respect to the resultant velocity vector of the body and

(ii) If the particle has both translational and rotational velocity, a lift force may be produced. This is known as the magnus effect.

In the non-dimensional form, the equations of motion of the ejecta particles are:

\[ \frac{du^*}{dt^*} = -K(u^* v^* + v^* + v^*) \left( \frac{C_L}{C_D} \right) \]

\[ \frac{dv^*}{dt^*} = K(u^* v^* + v^* v^*) \left( \frac{C_L}{C_D} u^* - v^* \right) - 1 \]

where \( u^* \) and \( v^* \) are respectively the x- and the y-velocity component; \( g \) is in the \(-y\) direction; \( t^* \) is the non-dimensional time, \( C_L \) is the lift coefficient and \( C_D \) is the drag coefficient and \( K \) is the ejecta transport parameter which is defined as

\[ K = \frac{1}{2} \left( \frac{\rho}{\rho^0} \right) \left( \frac{\rho}{\rho_p} \right) C_D \]

where \( u_0 \) is the initial horizontal velocity by which all non-dimensional velocities are referred to, \( \rho \) is the density of the effective atmosphere, \( \rho_p \) is the density of the ejecta particle and \( \lambda \) is an effective size of the particle.

Equations (1) and (2) are solved with the initial condition \( t^* = 0 \):

\[ u^* = 1, \quad v^* = v^* = \frac{\rho}{\rho_p} = \text{constant} \]

After \( u^* \) and \( v^* \) are obtained, the trajectory can be obtained by simple integration.

Fig. 1 shows some trajectories of the particles without lift as a function of \( K \). These curves are similar to those in literature. Fig. 2 shows the trajectories with lift effect as a function of \( K \). The trajectories
with lift may differ greatly from those without lift, particularly when $K$ is large.

The results of this study suggest that there is a relatively narrow size range of ejecta (within a factor of 3 for a given lunch condition) below which the ballistic range can be dramatically reduced and the trajectories can be highly distorted. Reduced ballistic ranges of ejecta due to drag alone have been previously discussed\(^1\), \(^2\), but with lift, the range may increase or decrease according to the value of $K$, $C_L/C_D$ and $v_o^2$. Furthermore, the highly distorted, looped trajectories revealed by this study is uniquely characteristic of the inclusion of lift.

There are three conditions where lift/drag can become important: ejecta traveling through a pre-impact atmosphere environment; ejecta traveling through any impact-generated temporary atmosphere; and ejecta traveling at different rates/angles through the general ejecta flow field. The first condition may not be met during early-time ejection when ballistic shadowing may be important, but is probably met as the ejecta disperse with distance\(^2\). In such a case, the looping trajectories would result in the temporary dispersion of a portion of the small size ejecta high in the atmosphere, perhaps behaving like an ash flow\(^6\). The second condition requires knowledge of the dynamical history of impact-generated volatiles, which presently is poorly known, but may result in the modified trajectories during early stages of crater growth. The third condition involving velocity/angle dispersions within the crater ejecta flow field also has not been studied in detail. However, in laboratory-scale impacts such dispersions are produced during the final stages of crater excavation in targets with near-surface variable strength\(^5\) and relatively small dispersions in large cratering events may produce considerable interactions\(^6\). Relatively small velocity dispersions within the ejecta curtain could significantly increase the size of affected ejecta owing to the possible large effective density within the curtain. The possible significance of such effects on ejecta emplacement in different environments are under further study.

References
EFFECTS OF LIFT FORCE ON THE EJECTA TRANSPORT

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\[ \frac{v_0}{u_0} = 0.25 \]
\[ \frac{c_L}{c_D} = 0.0 \]
\[ \frac{\rho^*}{\rho_p^*} = \text{CONSTANT} \]

Fig. 1. Trajectory of ejecta without lift effect

\[ \frac{v_0}{u_D} = 0.25 \]
\[ \frac{c_L}{c_D} = 2.0 \]
\[ \frac{\rho^*}{\rho_p^*} = \text{CONSTANT} \]

Fig. 2. Trajectory of ejecta with lift effect