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MODELING THE EXPLOSION OF THE TUNGUSKA METEORITE

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Abstract

Full Text

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Astronomy

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MODELING THE EXPLOSION OF THE TUNGUSKA METEORITE

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As a result of extremely labor-intensive expeditionary work in 1958–1965, a map was compiled of the damaged forest in the region of the fall of the Tunguska meteorite; the contours of the destruction area and the directions of the fallen trees at various points were established ($^{1-3}$). In all, over an area of 2200 km^2, by means of field survey, the azimuths of about 40,000 trunks that fell on June 30, 1908, were measured.

Fig. 1. Field of directions of forest fall. **1** —epicenter as determined on the ground and the zone of standing forest; **2** —projection of the trajectory according to astronomical data.

A summary of the results now available is presented in Fig. 1, where each arrow represents the average of 10–150 azimuth measurements. The character of the Tunguska blowdown leaves no doubt that it was produced by a powerful air wave with energy of the order of $4 \cdot 10^{23}$ erg ($^{4-7}$), whose source was located at some height above the ground.

The field of directions (Fig. 1) evidently characterizes the motion of the shock-wave front near the Earth' s surface. In contrast to what can be

Fig. 2. Arrangement of the cord and the model before the explosion; detonation proceeds from top to bottom. The distance between rows of model trees is 5 cm

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Fig. 3. Plan-view photograph of the blowdown field at an inclination of 30° and a fourfold enlargement in the cone. The boundaries from the concentrated and axial explosions, performed separately, are indicated.

Figure 3: Fig. 3. Plan-view photograph of the blowdown field at an inclination of 30° and a fourfold enlargement in the cone. The boundaries from the concentrated and axial explosions, performed separately, are indicated.

one should expect from a point air explosion; it is characterized by an eccentric position of the epicenter and the presence of wing-petals, in which a deviation from centrality by several degrees is noticeable. These features can be explained by assuming that the shock wave is, in its origin, a ballistic wave caused by the supersonic motion of a meteoric body in the atmosphere and intensified at the end as a result of its breakup, or violent fragmentation ([4,8,9]).

In the model experiments the ballistic wave was reproduced by the explosion of a detonating cord having a linear explosion energy (per unit length) $e_l = 6.3 \cdot 10^9$ erg/cm and a detonation velocity of 7–8 km/sec. The linear explosion energy of the cord at the end was increased severalfold by an additional charge of explosive. The cord was placed obliquely and ended at a certain height h above the model forest. The trees were simulated by flexible inelastic wires 3 cm high, furnished with a cylindrical plastic "crown" (Fig. 2). Under the action of the wave the wires bent, thereby marking the field of directions orthogonal to the wave front.

The closest similarity between the model fall field and the Tunguska one was achieved with an inclination $\alpha = 30^\circ$ to the horizon, an end height $h = 24$ cm, and an increase of e_l at the end by a factor of 4 (Fig. 3). Explosions of the concentrated terminal charge and of the homogeneous cord, carried out separately, show that this pattern is formed, in general, by a simple superposition of the corresponding fields. A point charge gives a circular central fall field with an epicentral zone where no fall is present. An elongated terminal charge (1:10) also forms a practically central field, but one slightly elongated perpendicular to its length. The fall from an axial explosion has the form of characteristic wings to the sides of the projection of the trajectory and is not central. Its shape is sufficiently stable under changes in inclination. Sharp differences (from that shown in Fig. 3) occur only at $\alpha \leq 10^\circ$ and $\alpha \geq 60^\circ$. This fall forms the rear part of the field.

Consideration of the experimental fields makes it possible to conclude that the isochrones of the wave front on the plane of the model are satisfactorily represented by sections of a cone expanding from the axis of the explosion and closed below by a hemisphere (Fig. 2).

Fig. 3. Plan-view photograph of the blowdown field at an inclination of 30° and a fourfold enlargement in the cone. The boundaries from the concentrated and axial explosions, performed separately, are indicated.

In that part of the field where the ballistic wave acts (Fig. 4), the streamlines are orthogonal trajectories to the family of elliptical isochrones, which explains the eccentricity of this part of the field. In its forward part the streamlines degenerate into straight lines emerging from the epicenter.

The indicated pattern is somewhat disturbed near the epicenter, which is expressed in its smearing backward along the projection of the trajectory. This is caused by the character of diffraction at the end of the cord, and also by the fact that the real wave, unlike a cone, has a certain convexity of the generators, since its velocity initially decreases and approaches the speed of sound only at some distance from the source.

The mechanism of formation of the petals (wings) is explained as follows. The vertical rods on the plane of the model are acted upon by the incident and reflected waves, and in the region of irregular reflection by the head wave formed as a result of their interaction. As is known, when a shock wave acts on "thin" objects (trees, rods), the principal damaging factor is the velocity pressure $q = \rho u^2$ behind the wave front (^{10}). At present there are experimental determinations of the magnitude of the horizontal component of the velocity pressure in ground explosions (^{10}) as a function of the excess pressure of the incident wave p and the angle of incidence θ. The function

$$q = q(p, \theta)$$

is characterized by a sharp maximum at $\theta \approx 45$—$55°$, i.e., at the beginning of irregular reflection.

Figure 4 shows isolines of the angle θ formed by the front of the incident conical wave with the plane of the model. The lines of equal excess pressures p, evidently, coincide with the isochrones of the front. Using the curvilinear coordinates p and θ, one can construct isolines of the horizontal velocity pressure on the plane of the model (Fig. 4). Their system corresponds to the experimentally observed contour of blowdown. In the experiment the boundary of blowdown passes approximately at $q \approx 0.35$ kg/cm^2.

The preferential propagation of the ballistic wave in the direction away from the projection of the trajectory had already been suspected earlier in considering acoustic phenomena caused by low bolides (^{11}). But in the experiment the axial asymmetry of the corresponding field was revealed most sharply. It is interesting that the azimuth of the projection of the trajectory of the Tunguska meteorite, determined as the axis of symmetry of Fig. 1 and equal to 295°, coincides to within a degree with recent determinations of the meteorite radiant by astronomical methods (^{9}).

Fig. 4. Diagram of the blowdown field for $\alpha = 30°$: xO —projection of the cord, O —end of the cord, yy —geometrical boundary of the conical wave, a —isochrones of the front, b —streamlines, c —lines of equal θ, d —isolines q

The pattern of the action of the ballistic wave on the surface, presented in Fig.

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4, admits a similar transformation with a change in the explosion energy. For both a cylindrical explosion and a ballistic wave,

$$p = f\left(\frac{\sqrt{e_l}}{r}\right),$$

where r is the distance to the axis. Therefore, for natural values of q and α, the linear dimensions x and y increase by the same factor as $\sqrt{e_l}$ increases. In the case of a change in α, a similar transformation is possible in the coordinates ρ and θ.

Thus, the blowdown of the forest at the site of the fall of the Tunguska meteorite can be explained by the wave of an axial explosion (a ballistic wave), and the projection of the axis is clearly determined by the form of the blowdown field. The increase in the linear energy of the explosion (ballistic wave) in the final part of the trajectory is comparatively small. It corresponds to an increase in the cross-sectional area of the moving body by only several times, which is naturally interpreted as its fragmentation.

Committee on Meteorites
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