PROBLEM OF THE TUNGUSKA METEORITE

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The main characteristic of the Tunguska meteorite was the liberation of $E = 10^{16}$–10^{17} J of energy into the atmosphere at an altitude of not less than 5000 m [1-4]. The resulting destruction, described by the generally accepted terminology "collapse of the forest," had an approximately centrally symmetric shape, and in addition, trees without branches remained standing, a so-called "telegraph forest," at the center of the zone [1, 2]. The destruction zone turned out to be the same as if a stationary spherical charge was exploded at an altitude above 5000 m [3, 4]. There were no traces of the meteorite and a crater on the earth. The puzzling nature of the Tunguska catastrophe attracted the attention of scientists more than 10 years after it happened. Before that, the Tunguska catastrophe was not thought to differ from many other previous well-known landings of large meteorites. As new puzzling factors relating to the Tunguska meteorite were made known, the number of investigations, expeditions, and publications concerned with this phenomenon began to increase rapidly.

In 1952 Academician M. A. Lavrent'ev stated two very important principles relating to the formation of a shock wave.

1. In the collapsed forest zone the parameters of the shock wave created by a fast moving dust cloud would not differ from the parameters of a shock wave formed by a gas cloud with identical velocity and density fields.

2. At the boundary of the region of destruction (in the collapsed forest zone), the shock wave contours showing equal values of the parameters will have a centrally symmetric shape with a center displaced by a distance l from the location of the interaction of the cloud with the atmosphere in the direction of motion of the cloud. The magnitude of l was determined in the experiments described below and it depended on the mass of the cloud.

In order to obtain a gas or a dust cloud, moving in a forward direction, it turned out to be easiest to explode a thin disk of explosive in front of a screen. It is known that when such an explosive is detonated, the action of the explosion is well directed. The detonation products move primarily in a direction perpendicular to the surface. At the initial instant, the energy of the explosion is transformed into kinetic energy of translational motion of the detonation products. The gas cloud gradually gives up its kinetic energy to an increasing quantity of air. A shock wave with the maximum degree of compression $(\gamma+1)/(\gamma-1) \simeq 6$, where γ is the adiabatic index for air, moves at a high velocity in front of the products. The trajectories of the product particles or of the particles in the dust cloud formed by the layer of sand on the disk, as well as air behind the wave front, depend insignificantly on the initial velocities, to the extent that the degree of compression is constant. For this reason, experimenting with relatively low velocities, obtained with the explosion of a TG 50/50 charge in front of a screen ($\simeq 2.5$ km/sec), it is possible to model velocities on the order of the orbital velocity.

In order to measure the magnitude of the positive half wave of the pulse momentum, we used mechanical pulsimeters measuring $I = \int_0^{t_0} p\, dt / (p(t_0) = 0)$. The pulsimeters were intended to perform measurements at a distance on the order of $50r_0$ and greater from the charge (r_0 is the radius of the charge with the same mass as in the case of the disk). They were positioned in a zone where the lateral pulse on the housing did not effect the precision of the measurements.

It is clear that with the explosion of a spherical explosive charge, the equal pulse momentum lines form circles. Figure 1 schematically shows equal pulse momentum lines, recorded in the experiment, for the explosion of a charge at a screen at the point O. It is evident that they represent, to within a known degree of precision, arcs of concentric circles centered at the point O_1. Control experiments with spherical charges having the same mass showed that a flat charge at the screen gives at large distances the same pulse momentum field as a spherical charge with the same mass displaced along the axis by a distance $l \simeq 50r_0$.

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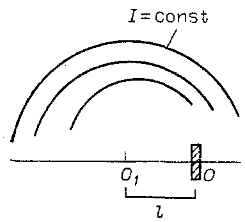

Fig. 1

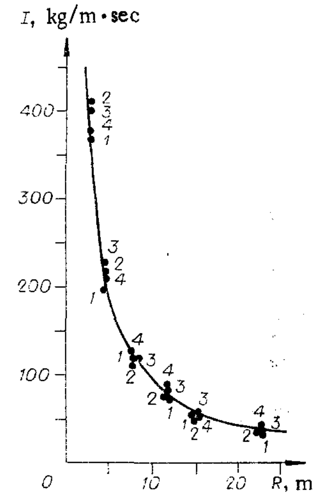

Fig. 2

Now, let us proceed from the model to nature. For the orbital velocity, the Tunguska meteorite must have a mass exceeding 10^9 kg. In order to determine the displacement in the center of the explosion of the meteorite ($L = 50R_0$), we find the radius R_0 of a spherical TG 50/50 charge with a mass of 10^9 kg. It should be noted here that it is the mass that is important for the quantity L and not the energy. These calculations give $L \simeq 3000$ m.

If it is assumed that at an altitude of 12,000 m the cloud will begin to disperse according to the laws of hydrodynamics, then the magnitude of the displacement L_1 increases in proportion to the square root of the ratio of the densities of air under normal conditions and under the conditions at an altitude of 12,000 m. This correction doubles the displacement. Thus, a dust cloud with a mass greater than 10^9 kg, entering into the upper, relatively dense layers of the atmosphere, creates the effect of a spherical explosion at a point displaced by a distance $L_1 = 6000$ m along the flight path from the location at which it enters the dense layers of the atmosphere. Taking into account the angle at which the meteorite enters into the atmosphere ($\alpha \simeq 17°$), the center of symmetry of the pulses will occur at an altitude of about 10,000 m from the earth's surface [3, 4].

In order to obtain an additional check on the formation of a shock wave due to the action of a dust cloud, we carried out a series of explosions of extended charges with a mass of 10 kg in a shell made of sand. The coefficient k, equal to the ratio of the weight of the explosive charge to the total weight of the charge and the shell, in the experiments constituted 20, 30, 50, and 100%. The charges were placed in a vertical position; correspondingly, the shock wave had an axisymmetric shape. Figure 2 shows the results of experiments for measurements with the charge length to charge diameter ratio equal to 5. The numbers 1, 2, 3, and 4 denote the points corresponding to charges with k=20, 30, 50, and 100%. As these data show, the pulse momentum field remains unchanged with the introduction of a sand shell at a sufficient distance away from the charge. Similar results were obtained with experiments using a relative elongation of the charge equal to 1.5.

Determination of the peak pressures in the shock wave by computing them from the velocity fields behind the wave front shows that beginning at the distance $60r_0$, charges with equal filling factors have equal peak pressure fields, i.e., the positive half waves remain identical with equal energies for different dust clouds at distances exceeding $60r_0$.

Thus, the results of the experiments presented above support the principles asserted above and show that in order for the pulse momentum fields to be equal, it is enough for the products and the dust cloud to have the same kinetic energy. Due to the coincidence of the peak pressures at distances exceeding $60r_0$, we can assume that in view of the equality of the pulse momenta the wave profiles coincide as well. For comparison, we note that the forest collapse occurred at distances exceeding $100r_0$.

In [5], the author gives a great deal of attention to the analysis of the forest collapse, and taking into account geomagnetic effects, he asserts that the energy was liberated at an altitude not less than 5000 m in a region not less than 5000 m in size, and therefore, this must be a spherical explosion. In doing so, he stubbornly looks for arguments supporting the liberation of an unusual internal energy in the meteorite.

It is desirable to explain the Tunguska catastrophe introducing a minimum number of unusual ideas. Academician V. I. Vernadskii first stated the ideal of a dust origin for the Tunguska meteorite in 1941 [6].

However, later, he did not persist in his assertion. In 1975, Academician G. I. Petrov [7] developed a theory of the Tunguska meteorite based on the injection of a large snow mass with a low density into the atmosphere. The most probable velocity of the meteorite must equal the orbital velocity, taking into account the fact that bright nights occurred in different parts of the earth even before the Tunguska catastrophe [3, 4].

In order to calculate the maximum possible path length (upper bound) transversed by the dust mass in air, taking into account the approximate nature of the quantitative data used, the main source of error for which stems from the impossibility of determining with greater precision the energy liberated in the atmosphere, and neglecting smaller sources of error, such as the effect of compressibility of air and the shape of the meteorite along its path length in the atmosphere, we used the expression (1), a formula of M. A. Lavrent'ev for the penetration depth of a jet [8]:

$$\frac{dl}{dh} = \sqrt{\frac{\rho_0}{\rho_1}}, \qquad (1)$$

where dl is element of path length in air penetrated by an element of the meteorite diameter dh; ρ_0, density of the meteorite; ρ_1, density of air.

For the diameter of the meteorite calculated from the condition $E = 10^{17}$ J, a bulk density of 2000 kg/cm^3 and a velocity of 10^4 m/sec, the path length over which it decelerates in the upper layers of the atmosphere is $\sim 10^4$m. However, , actually, this deceleration path length could be much shorter. Taking into account the fact that the dynamic pressure attains a maximum in the frontal region facing the atmosphere, while on the periphery, it practically equals zero, we can assume that the porous mass of the meteorite will be exploded from within by compressed air and will decelerate over a path length that is several times shorter than would follow from a calculation involving a deformable, but impermeable body.

The problems concerning the Tunguska meteorite that are difficult to explain include, in particular, the origin of the forces preventing dispersion of the particles under the action of electrostatic forces. We cannot exclude the possibility of a meteorite made up of particles having a magnetic moment. A mass made up of such magnetic dipoles must have properties similar to those of a liquid drop and a density close to the bulk density of the constituent particles. The force lines will be closed within the mass.

We should note that the Tunguska meteorite must break apart not under the action of slowly propagating heat wave, but under the action of the oncoming air pressure. If the meteorite mass has a low strength, a stress wave in the body of the meteorite propagates several times more rapidly than a heat wave. After dispersing, the dust cloud gives up its energy into a shock wave over a relatively short path.

Thus, it has been shown that a shock wave formed by a dispersing meteorite is equivalent to a point explosion with an energy equal to the kinetic energy of the meteorite (10^{17} J) at a point displaced in the direction of its initial velocity by a distance $\approx 50r_0$ from the location at which it entered the dense layers of the atmosphere.

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