COMPUTATION OF A POSSIBLE TUNGUSKA'S STREWN FIELD

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Introduction: On June 30, 1908, at about 0h 14.5 m UTC, the Tunguska Event (TE) occurred, most likely caused by the fall of a small stony asteroid of about 50–80 m in diameter over the basin of the Tunguska River (Central Siberia). The first expedition was made by the geologist Leonid Kulik 19 years after the event, and macroscopic meteorites have never been found around the epicenter. However, local eyewitnesses of TE tell a different story: they observed a stone that appeared from ''nowhere'' in the destroyed forest, and several local Evenkis reported fresh furrows in the epicenter with stones in the furrow walls [1]. So, the lack of macroscopic meteorites is not proof of the complete disintegration of the TCB: the time elapsed from the fall to the first Kulik expedition was 19 years, enough time for any little craters and meteorites to be buried by mud and vegetation.

Using the Chelyabinsk event as a guide to test a fall model for macroscopic fragments, we will delimit a possible strewn field to search for possible macroscopic meteorites belonging to the Tunguska cosmic body or TCB [2].

A test on the Chelyabinsk event: As a first step, we will use the data about the Chelyabinsk event (CE) to test the dark flight and strewn field computation tools.

About CE, various individual fragmentations have been recorded between 40 and 30 km of altitude: after the main airburst, around 29.7 km, about 20 fragments emerged from the disruption clouds. The main boulder was destroyed at an altitude of 22 km, while fragment F1 continued the fall in the densest layers of the atmosphere, survived a maximal dynamic pressure of about 15 MPa at an altitude of about 20 km, and began the dark flight phase at about 12.6 km height with a speed of 3.2 km/s. The fragment F1 from the CE was recovered in Lake Chebarkul on Oct 16th and found to weigh about 570 kg.

Using our model for the dark flight, the computed impact coordinates for F1 are long. 60.321◦ ± 0.003◦ N and lat. 54.962◦ ± 0.002◦ E with the asymptotic value of drag coefficient equal to $\Gamma \approx 0.775$. These impact coordinates are about 17.2 km away from the start of the dark flight and about 300 m from the observed impact point, i.e. the computed impact point is within 1 sigma from the observed one.

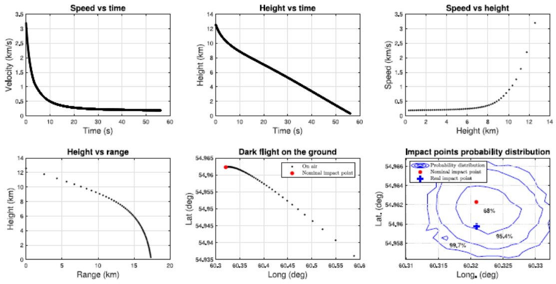

Figure XX. The dark flight model for the F1 fragment of the Chelyabinsk event. From the probability distribution of the impact points (bottom right box), we see that the nominal impact point is in the area within which 68% of the virtual impact points fall.

The Tunguska event: About the TE, seismic and barometric registrations were recorded immediately after the event, and data on forest devastation about directions of flattened trees and charred trees were collected in a century of expeditions. The time of the event was established reasonably well from the seismic and barometric recordings. The most widely quoted magnitude range of the developed energy, based on historic barograms, seismic records, and forest damage compared with nuclear airbursts, is between 10 and 40 Mt, with a most probable value of about 15 Mt [3]. From forest devastation and different arrival times for Rayleigh and SH body waves recorded at Irkutsk, an explosion height of about 8.5 km was obtained [4]. The geographic coordinates on the ground of the explosion in the atmosphere (the so-called epicenter) were set by the azimuth distribution of the flattened trees, while from the symmetry of the devastation area and eyewitness data, the range for trajectory azimuth and inclination above Earth surface was set [5].

TCB's maximum dynamic pressure: considering the range of the possible atmospheric trajectories, the TCB's speed cannot be greater than 35–40 km/s because otherwise, the body could not belong to the Solar System [5]. Assuming that TCB was a stony near-Earth asteroid, the most probable speed in the atmosphere is between 11 and 20 km/s and considering the small dimension – below the cohesionless spin-barrier limit of about 150 m − this leads us to hypothesise that most likely was a monolithic block. The space exploration of asteroids, such as Ryugu and Bennu, confirms monolithic blocks with dimensions up to several tens of meters.

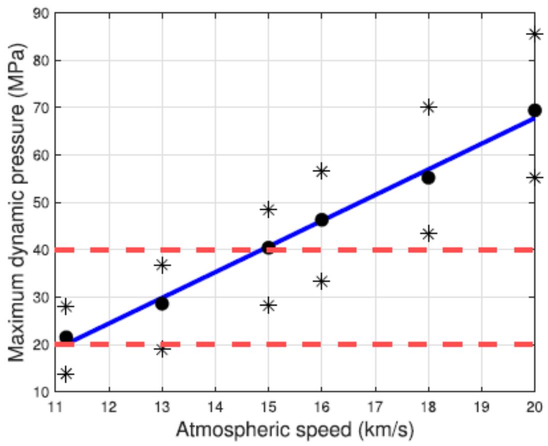

Figure XX. The maximum dynamic pressure as a function of atmospheric entry speed for a TCB with a kinetic energy of 15 Mt, trajectory inclination of 35°, pancake factor 7.5 and airburst height in the range 8–9 km. The two horizontal dotted lines indicate the lower and upper limits of the Carancas's mean strength, while the asterisks indicate the maximum dynamic pressure for models with pancake factors 5 (up) and 10 (down).

The results of our calculations made with a pancake model [6][7], taking into account the Weibull statistics for a monolithic TCB with kinetic energy of 15 Mt, atmospheric entry velocity between 11 and 20 km/s and an average initial strength in the range 3–70 MPa (so that the airburst occurs at an altitude of 8–9 km), tell us that a macroscopic fragment with an average strength between 14–85 MPa and an initial mass of 5000 kg (diameter of about 1.4 m), would have managed to survive the airburst and reach the ground. The maximum strength of the fragment is approximately twice the maximum strength estimated for the Carancas fall in 2007; therefore, it is a value that is still physically possible. In this scenario, the arrival speed of the fragment on the ground is between 0.8 and 0.5 km/s, high enough to penetrate the Siberian permafrost by digging a tunnel with a volume a few hundred times greater than that of the meteoroid and remaining buried there.

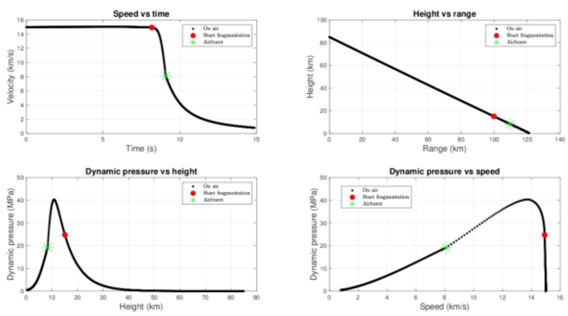

Figure XX. The Tunguska fall model with initial kinetic energy 15 Mt, height 85 km, speed 15 km/s, Γ = 0.58, mean density 3290 kg/m^3, diameter 69 m, inclination 35°, pancake factor 7.5 and TCB's mean strength 25 MPa. Duration of the pancake phase, from the fragmentation to the airburst, 0.9 s. The airburst is at 8.3 km, and the maximum dynamic pressure is 40.4 MPa. A fragment of 1.4 m diameter with a strength of 100 MPa touches the ground with a diameter of about 1.2 m at a speed of about 0.7 km/s.

Tunguska's strewn field: Where could these possible fragments have fallen? If we use the equations that describe the dark flight of meteoroids, taking into account the altitude of the explosion, which occurred at approximately 8.5 ± 1 km, the most probable speed for the fragments of 10 ± 3 km/s, the most likely inclination of 35° ± 5° and air resistance, then the answer is about 11 km northwest of the epicenter, around the coordinates 60.921° ± 0.02° N and 101.697° ± 0, 03°E, in an area that roughly covers 140 km^2: this is where one should look for possible large fragments of the TCB. Clearly, more than 100 years after the event, it would not be easy to find something considering that it would be necessary to excavate the Siberian permafrost, but the "hunt" for the Tunguska meteorites should resume: if a macroscopic fragment of the TCB could be recovered, the information that could obtain would clarify both the nature of the body and its origin beyond any reasonable doubt.

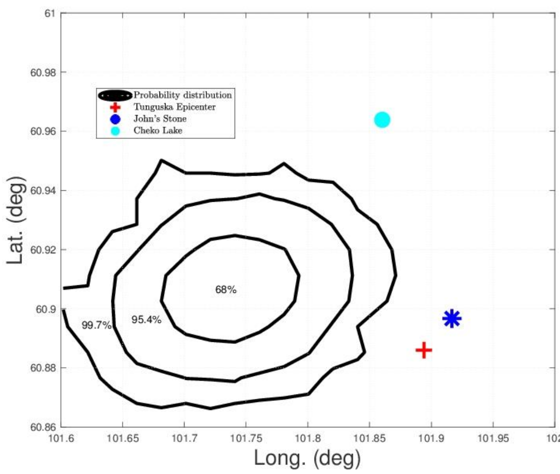

Figure YY. A possible Tunguska strewn field for about 1 m meteorites. The internal curve encloses an area with a probability of falling of 68% (1 sigma), the intermediate one of 95.4% (2 sigma), while the outermost one represents the area with a probability of falling of 99.7% (3 sigma). Cheko Lake is located approximately 3.5 km from the outer edge of the strewn field.

References: [1] Anfinogenov, J., et al., (2014), *Icarus* 243, 139–147. [2] Carbognani A. et al., (2024), *Icarus*, 408, 115845. [3] Vasilyev, N.V., (1998), *Planet. Space Sci.* 46, 129–150. [4] Ben-Menahem, A., (1975), Phys. Earth Planet. Inter. 11, 1–35. [5] Farinella, P., et al., (2001), *Astron. Astrophys*. 377, 1081–1097. [6] Chyba, C.F., Thomas, P.J., Zahnle, K.J., (1993), *Nature* 361, 40–44. [7] Hills, J.G., Goda1, M.P., (1993), *Astron. J.* 105, 1114–1144.