KOŠICE METEOROID INVESTIGATION: FROM OBSERVATIONAL DATA TO ANALYTIC MODEL

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Introduction. We present results on our investigation on the Košice meteorite – one of the recent falls with well derived trajectory and large number of recovered fragments. A fireball appeared over central-eastern Slovakia on February 28, 2010. The landing area was successfully computed on the basis of data from the surveillance cameras operating in Hungary and lead to a fast meteorite recovery [1]. 218 fragments of the Košice meteorite, with a total mass of 11.285 kg, have been documented [2]. Based on the statistical investigation of the recovered fragments bimodal Weibull, bimodal Grady and bimodal lognormal distributions are found to be the most appropriate for describing the Košice fragmentation process. The most probable scenario suggests that the Košice meteoroid, prior to further extensive fragmentation in the lower atmosphere, was initially represented by two independent pieces with cumulative residual masses of approximately 2 kg and 9 kg, respectively [2]. About 1/3 of the recovered Košice fragments were thoroughly studied, including magnetic susceptibility, bulk and grain density measurements reported in [3] revealing that Košice meteorites are H5 ordinary chondrites originating from a homogenous parent meteoroid.
To estimate the dynamic mass of the main fragment we studied the first integral of the drag and mass-loss equations, and the geometrical relation along the meteor trajectory in the atmosphere. By matching these equations to the trajectory data [1] we determine key dimensionless parameters responsible for the meteoroid drag and ablation rate along its visual path in the atmosphere. These parameters allow us to estimate the preatmospheric mass, which is in good agreement with the photometric estimate derived in [1]. Throughout this study we permit changes in meteoroid shape along the trajectory. Additionally, we provide in-sights on the initial shape of the Košice meteoroid based on statistical analysis [4]. We also conclude that two to three larger Košice fragments of 500-1000 g each should exist, but were either not recovered or not reported by illegal meteorite hunters.

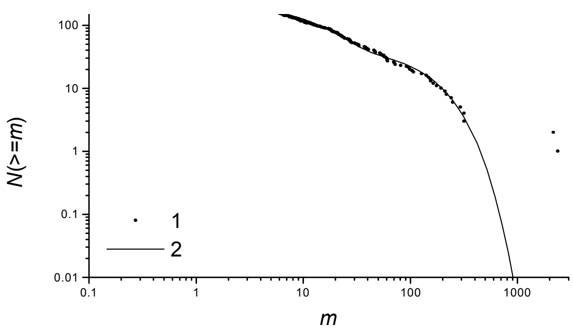
Košice - H5 ordinary chondrites [3]

Bulk and grain densities, porosities, and magnetic susceptibilities of 67 individuals of Košice H chondrite fall were measured. The mean bulk and grain densities were determined to be 3.43 g/cm^3 with standard deviation (s.d.) of 0.11 g/cm^3 and 3.79 g/cm^3 with s.d. 0.07 g/cm^3, respectively. Porosity is in the range from 4.2% to 16.1%. The logarithm of the apparent magnetic susceptibility (in 10^{-9} m^3/kg) shows narrow distribution from 5.17 to 5.49 with mean value at 5.35 with s.d. 0.08.
These results indicate that all studied Košice meteorites are of the same composition down to ~*g* scale without the presence of foreign (non-H) clasts and are similar to other H chondrites. Košice is thus a homogeneous meteorite fall derived from a homogeneous meteoroid.

F_W - Weibull bimodal distribution

$$F_W(m,\omega,\gamma_1,\mu_1,\gamma_2,\mu_2)=\omega\left[1-\exp\left(-\left(\frac{m}{\mu_1}\right)^{\gamma_1}\right)\right]+(1-\omega)\left[1-\exp\left(-\left(\frac{m}{\mu_2}\right)^{\gamma_2}\right)\right]$$

ω - weighting factor, $M_\bullet$ and $\mu_\bullet$ - subtotal mass and average mass for the 1st and 2nd modes, respectively

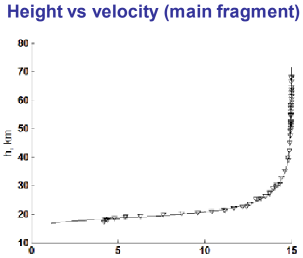


Complementary cumulative number of fragments $N(\geq m)$ vs m (decimal logarithm scale) for the sample. 1 – Observed data, 2 – Bimodal Weibull distribution with the weighting factor ω=0.8, $\gamma_1=\gamma_2$=1.14 and μ_1=13.1, μ_2=140.

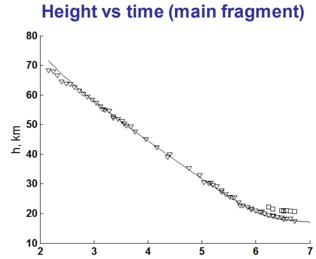
Results of calculations

The following values were obtained: V_e=14.979 km/s, sin γ=0.87, α=2.99, β=3.35, $\delta=2.98\cdot10^{-2}$ s^2/km^2

Height vs velocity (main fragment)



Height vs time (main fragment)



Analytical solution with parameters found by the method (solid lines) compared to observation results (symbols)

Aerodynamic model

The equations of motion:

$$M\frac{dV}{dt}=-\frac{1}{2}c_d\rho_a V^2 S,\quad \frac{dh}{dt}=-V\sin\gamma,\quad H^*\frac{dM}{dt}=-\frac{1}{2}c_h\rho_a V^3 S$$

$$\Rightarrow\quad m\frac{dv}{dy}=\frac{1}{2}c_d\frac{\rho_0 h_0 S_e}{M_e}\frac{\rho v s}{\sin\gamma},\quad \frac{dm}{dy}=\frac{1}{2}c_h\frac{\rho_0 h_0 S_e}{M_e}\frac{V_e^2\rho v^2 s}{H^*\sin\gamma}$$

$\rho=\exp(-y)$

$s=m^\mu$, μ=const

M – body mass, ***V*** – body velocity, ***h*** – height above the planetary surface, γ – angle between the trajectory and the horizon, ***S*** – area of the body middle section, H^* – effective destruction enthalpy, ρ_a – atmospheric density, c_d and c_h – coefficients of drag and heat exchange
Dimensionless variables: $m=M/M_e$, $v=V/V_e$, $s=S/S_e$, $y=h/h_0$, $\rho=\rho_a/\rho_0$: M_e, V_e, S_e – pre-entry values, h_0 – height of the homogeneous atmosphere, ρ_0 – atmospheric density near the planetary surface
Analytic solution with initial conditions $y=\infty$, v=1, m=1:

$$m=\exp\left(-\frac{\beta}{1-\mu}(1-v^2)\right),\quad y=\ln\alpha+\beta-\ln\frac{\Delta}{2}$$

$$\Delta=Ei(\beta)-Ei(\beta v^2),\ Ei(x)=\int_{-\infty}^{x}\frac{e^z dz}{z}$$

$$\alpha=\frac{1}{2}c_d\frac{\rho_0 h_0 S_e}{M_e\sin\gamma}$$ **ballistic coefficient**

$$\beta=\frac{1}{2}(1-\mu)\frac{c_h V_e^2}{c_d H^*}$$ **mass loss parameter**

Initial mass computation:
$$M_e=\left(\frac{1}{2}c_d\frac{\rho_0 h_0}{\alpha\sin\gamma}\frac{A_e}{\rho_m^{2/3}}\right)^3\approx1500kg$$

Probabilities for missing fragments for Košice meteorite

Distribution	Probability of singular fragment to occur within the gap (318; 2167.4)	Expected frequency	Probability of complete absence of any fragment from the set within the gap	Probability of 5 or fewer (at least 1) fragments to occur within the gap
Lognormal	0.011	2.34	0.095	0.874
Lognormal bimodal	0.025	5.42	0.004	0.537
Weibull bimodal	0.016	3.41	0.032	0.839
Grady bimodal	0.029	6.81	0.001	0.324

References: [1] Borovička J. et al. 2013. Meteoritics and Planetary Science 48(10): 1757-1779. [2] Gritsevich M. et al. 2014. Meteoritics and Planetary Science 49(3): 328-345. [3] Kohout T. et al. 2014. Planetary and Space Science 93-94: 96-100. [4] Vinnikov V. et al. 2014. 45th LPSC Abstracts. LPI Contribution No. 1777, p.1439.
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