Statistical approach to meteoroid shape estimation

V. Vinnikov (1), **M. Gritsevich** (1,2,3,4), L. Turchak (1)
(1) Dorodnicyn Computing Centre of the Russian Academy of Sciences, Moscow, Russia (vvinnikov@list.ru),
(2) Finnish Geodetic Institute, Masala, Finland (maria.gritsevich@fgi.fi),
(3) Moscow State University of Geodesy and Cartography, Moscow, Russia
(4) Institute of Physics and Technology, Ural Federal University, Ekaterinburg, Russia.

Introduction

The estimation of initial meteoroid shape is very important, since it affects the meteoroid pre-entry mass, terminal meteorite mass, and fireball luminosity. However, its reconstruction is complicated. The meteorite fragments of the same meteoroid do not match each other due to incomplete recovery as well as melting and ablation. Nevertheless, many studies consider the ablation to be weak after the major fragmentation. Therefore, the resulting mass distribution does not experience significant changes. Moreover, the brittle shattering process exhibits fractal properties for scaling mass sequences described by power law.

Estimation of Initial Shape

We consider a meteoroid shape estimation technique based on statistical laws of distribution for fragment masses. The idea to reconstruct initial meteoroid shape comes from the experiments demonstrating that brittle fracturing produces multiple fragments of size lesser than or equal to the least dimension of the body. The number of fragments depends on fragment masses as a power law with scaling exponent β_0 and exponential cutoff

$$F_c\left(m\right) = C{\cdot}m^{-\beta_0}{\cdot}\exp\left(-m/m_U\right),$$

where $C = \left(\beta_0 - 1\right){\cdot}m_L^{\beta_0 - 1}$ is a normalization constant, $m_U > m_L$ is an upper cutoff fragment mass and m_L is an arbitrary lower mass limit, acting as an additional constraint for undersampled tiny unrecoverable fragments. Since the empirical density distribution of recovered fragment masses is discrete, we convert it to the piecewise complementary cumulative distribution function (see [1]). Then, we conduct a normalization procedure, equaling fragment masses at the point of lower mass constraint. Next, the least-squares method is applied to fit the sought-for analytical distribution into the empirical one

$$S\left(\beta_0, j.m_U\right) = \sum_{i=j}^{N}\left[F_c\left(m_i\right) - \left(N - j\right)/m_j\right]^2.$$

Once the mass constraints and cutoff value are obtained, we estimate dimensionless shape parameter d and size proportions a_x, a_y, a_z for initial pre-entry meteoroid

$$d = 1 + 2\left(a_x a_y + a_y a_x + a_z a_x\right)\left(a_x^2 + a_y^2 + a_z^2\right)^{-1},$$

$$0.13d^2 - 0.21d + \left(1.1 - \beta_0\right) = 0.$$

Thus the scaling exponent β_0 essentially indicates the initial form of the fragmented body. We successfully applied the technique of scaling analysis to the empirical data on the mass distributions for Kosice [2], Sutters Mill [3] and Bassikounou [4] meteorites (see Table 1).

Table 1: The derived shape parameters for the considered meteoroids.

Meteoroid	β_0	d	$a_x : a_y : a_z$
Košice	1.53	2.80	2.00 : 1.69 : 1.00
Sutters Mill	1.51	2.76	2.13 : 1.58 : 1.00
Bassikounou	1.32	2.34	2.98 : 1.13 : 1.00

References

[1] Oddershede, L., Meibom, A., Bohr, J., Europhys. Lett, 43, 598, 1998.
[2] Gritsevich, M., Vinnikov, V., Kohout, T., et al., Meteoritics and Planet. Sci, 49(3), pp. 328–345, 2014.
[3] Jenniskens, P., Fries, M.D., Yin, Q.-Z., et al., Science, 338(6114), pp. 1583–1587, 2012.
[4] Buhl, S., Baermann, M., Niger Meteorite Recon, 2007, www.niger-meteorite-recon.de