A PRE-ENTRY SHAPE ESTIMATION FOR PUERTO LÁPICE AND VILLALBETO DE LA PEÑA METEORITES VIA STATISTICAL DISTRIBUTION OF FRAGMENT MASSES

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Introduction: One of the challenging physical problems is the estimation of the pre-entry shape of a meteoroid, since the detailed hypersonic body interaction with an atmosphere (e.g. shape of the bow shock wave) is unobservable directly. However, the final results of the interaction are observable and measurable in the form of fragment masses. The approach to estimate the shape is based on the statistical mass distributions of the recovered fragments is presented. The power law with exponential cutoff is fitted to the empirical fragment distribution function to obtain the scaling index. An empirical quadratic equation relates the scaling index to the shape parameter, expressing the proportions of the of the initial unfragmented body. The technique for estimating the initial shape of a disintegrating body is based on the results of experiments on brittle fragmentation with the size of fragments being smaller than or equal to the minimum linear dimension of the body [1].

Solution Methods: We apply this technique to study a set of fragments of the Puerto Lápice and Villalbeto de la Peña meteorites and compare the results with the counterparts of other meteorite shapes. The discrete distribution of fragment masses $\{m_i\}_{i=1}^{N}$ is approximated by a power law with exponential cutoff

$$F(m) = \frac{N-j}{m_j}\left(\frac{m}{m_j}\right)^{-\beta_0} \exp\left(-\frac{m-m_j}{m_U}\right),$$

where β_0 is a scaling index, m_j is the lower limit of sample completeness, and $m_U > m_j$ is the upper exponential cutoff mass.

The scaling index β_0 and the upper cut-off mass m_U are obtained by fitting to the known fragment distribution via the least squares method

$$S(\beta_0, j, m_U) = \sum_{i=j}^{N}\left[\frac{N-j}{m_j}\left(\frac{m}{m_j}\right)^{-\beta_0} \exp\left(-\frac{m-m_j}{m_U}\right) - \frac{N-j}{m_j}\right]^2$$

by calculating the partial derrivates $\partial S/\partial\beta_0$, $\partial S/\partial m_U$, $\partial^2 S/\partial\beta_0^2$, $\partial^2 S/\partial m_U^2$, $\partial^2 S/\partial\beta_0\partial m_U$.

The least squares are solved numerically via Newton iterations to find β_0^* and m_U^* that correspond to $\frac{\partial S}{\partial \beta_0} = 0$ and $\frac{\partial S}{\partial m_U} = 0$:

$$\left.\begin{pmatrix} \frac{\partial^2 S}{\partial\beta_0^2} & \frac{\partial^2 S}{\partial\beta_0\partial m_U} \\ \frac{\partial^2 S}{\partial\beta_0\partial m_U} & \frac{\partial^2 S}{\partial m_U^2} \end{pmatrix}\right|_{\binom{\beta_0}{m_U}^{(k)}} \begin{pmatrix}\beta_0 \\ m_U\end{pmatrix}^{(k+1)} = \left.\begin{pmatrix} \frac{\partial^2 S}{\partial\beta_0^2} & \frac{\partial^2 S}{\partial\beta_0\partial m_U} \\ \frac{\partial^2 S}{\partial\beta_0\partial m_U} & \frac{\partial^2 S}{\partial m_U^2} \end{pmatrix}\right|_{\binom{\beta_0}{m_U}^{(k)}} \begin{pmatrix}\beta_0 \\ m_U\end{pmatrix}^{(k)} - \left.\begin{pmatrix} \frac{\partial S}{\partial\beta_0} \\ \frac{\partial S}{\partial m_U} \end{pmatrix}\right|_{\binom{\beta_0}{m_U}^{(k)}}.$$

The obtained parameter β_0 is used in the empirical equation of the second order

$$0.13 d_m^2 - 0.21 d_m + (1.1 - \beta_0) = 0.$$

The dimentionless parameter d_m is related to the meteorite linear proportions a, b, c as

$$d_m = 1 + \frac{2(ab + ac + bc)}{a^2 + b^2 + c^2}.$$

We also provide an R-program that injests meteorite fragment masses in ascending order and returns the sought-for parameters β_0 and m_U as well as d_m and a, b, c.

Results: We compare the meteorite pre-entry shape estimated as linear proportions against the respective counterparts of Košice, Almahata Sitta, Bassikounou [2] and Sutter's Mill [3] meteorites.

References: [1] Oddershede L. et al. (1993) *Physical Review Letters.* 71:3107. [2] Vinnikov V. et al. (2015) *Proceedings IAU Symposium.* 306. [3] Vinnikov V. et al. (2014) *45th Lunar and Planetary Science Conference.*