Assessment of Meteoroid Pre-Atmospheric Diameter from Brightness Measurements Prior to Fragmentation.
C. O. Johnston¹ and E. C. Stern², ¹ NASA Langley Research Center, Hampton, VA 23681, ² NASA Ames Research Center, Moffett Field, CA 94035.

Introduction: At altitudes near 60 km, the velocity of a meteor remains essentially at its initial value regardless of the entry flight path angle, assuming a meteoroid larger than roughly 10 cm. Therefore, if the meteoroid remains unfragmented at these higher altitudes, the measured brightness at a given altitude is a function of the initial velocity and meteoroid diameter, as well as the ablation rate, meteoroid composition, meteoroid shape, and view angle. If it can be established that the measured brightness is weakly dependent on these latter four variables, then the brightness at a given altitude is only dependent on the meteoroid diameter and velocity. This relationship would allow the meteoroid diameter to be evaluated from the measured brightness at a specific altitude, assuming the velocity was also known. Because the impact of ablation at these higher altitudes has not yet changed the meteoroid diameter noticeably, the meteoroid diameter evaluated with this relationship may be assumed to equal the pre-atmospheric value. Establishing this relationship for meteoroids larger than roughly 10 cm is the goal of this paper.

Background: Knowledge of the pre-atmospheric diameter of a meteoroid allows its initial mass to be evaluated, assuming a meteoroid density and shape (usually a sphere). However, typically the initial mass of the meteoroid is evaluated directly instead of first computing the meteoroid diameter [1]. For most meteor events, which do not include recovered meteorites, three approaches are used to evaluate the pre-atmospheric mass. The first of these is the photometric mass approach, where the measured radiation integrated over the trajectory (\(E_{\text{rad}}\)) is assumed to represent a known fraction (\(\tau\), which is the integral luminous efficiency) of the initial meteor energy, which allows the initial meteor mass to be computed as \(M = E_{\text{rad}}/\tau\). Numerous past and recent studies [2, 3, 4] have tuned \(\tau\) values to match the photometric mass to other mass estimates, which have resulted in a potential orders-of-magnitude variation in \(\tau\). The challenge in accurately determining the luminous efficiency \(\tau\) is that it must be modeled through the complex fragmenting phase of the trajectory. This makes computational simulations of \(\tau\) infeasible except for unfragmented regions of the trajectory, which typically have a relatively small impact on \(E_{\text{rad}}\). In addition to the \(\tau\) uncertainty, the measured brightness, is obtained over a limited spectral range, which requires contributions from un-measured regions of the spectrum to be approximated. This approximation assumes a Planck function at a chosen temperature, such as 4500 or 6000 K. This uncertainty in \(\tau\) leads to a typically quoted factor of three uncertainty in the resulting photometric mass, which converts to roughly a ±50% uncertainty in the resulting diameter.

Another standard method for determining the meteoroids pre-atmospheric mass and diameter is the dynamic mass approach, which uses the ablation coefficient and deceleration profile of the meteor to assess an initial mass. This method was simplified to a least squares approach [5], requiring the determination of two terms, a mass loss and ballistic coefficient term, to minimize the deviation from the measured trajectory.

The third standard method for determining the meteoroids pre-atmospheric mass and diameter is the infrasound approach [6]. This approach correlates infrasound measurements resulting from a meteor to the initial meteor energy, which is used to evaluate the initial mass analogously to the photometric mass. The infrasound approach is limited by the availability of the infrasound measurement, as well as the conversion of the measurement to the total meteor energy, which faces similar challenges to \(\tau\) for an accurate definition.

As an alternative to these three methods, the present work develops an approach to evaluate the pre-atmospheric diameter, therefore allowing the initial mass to be inferred, using the radiation measured at a single altitude prior to significant fragmentation, as well as the velocity at that altitude (which may be approximated by the initial velocity for many cases). This approach avoids the complexity of modeling a parameter such as \(\tau\) through fragmentation.

The developed relationship, which is valid for entry velocities below 30 km/s and initial diameters greater than 10 cm, is written as \(D = 0.0556 \times 10^{-0.182M_{60km}} \times 0.562V_{60km}^{-0.0562} \times 10^{-0.182M_{60km}}\), where \(D\) is the initial meteoroid diameter in m, \(M_{60km}\) is the absolute visual magnitude measured at an altitude of 60 km, and \(V_{60km}\) is the velocity in km/s at 60 km.

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