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Physics-Based Modeling of Meteor Entry and Breakup

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ABSTRACT

A new research effort at NASA Ames Research Center has been initiated in Planetary Defense, which integrates the disciplines of planetary science, atmospheric entry physics, and physics-based risk assessment [1]. This paper describes work within the new program and is focused on meteor entry and breakup.

Over the last six decades significant effort was expended in the US and in Europe [2] to understand meteor entry including ablation, fragmentation and airburst (if any) for various types of meteors ranging from stony to iron spectral types. These efforts have produced primarily empirical mathematical models based on observations. Weaknesses of these models, apart from their empiricism, are reliance on idealized shapes (spheres, cylinders, etc.) and simplified models for thermal response of

meteoritic materials to aerodynamic and radiative heating. Furthermore, the fragmentation and energy release of meteors (airburst) is poorly understood.

On the other hand, flight of human-made atmospheric entry capsules is well understood. The capsules and their requisite heatshields are designed and margined to survive entry. However, the highest speed Earth entry for capsules is <13 km/s (Stardust [3]). Furthermore, Earth entry capsules have never exceeded diameters of 5 m, nor have their peak aerothermal environments exceeded 0.3 atm and 1 kW/cm².

The aims of the current work are: (i) to define the aerothermal environments for objects with entry velocities from 13 to >20 km/s; (ii) to explore various hypotheses of fragmentation and airburst of stony meteors in the near term; (iii) to explore the possibility of performing relevant ground-based tests to verify candidate hypotheses; and (iv) to quantify the energy released in airbursts. The results of the new simulations will be used to anchor said risk assessment analyses [4].

With these aims in mind, state-of-the-art entry capsule design tools are being extended for meteor entries. We describe: (i) applications of current simulation tools to spherical geometries of diameters ranging from 1 to 100 m for an entry velocity of 20 km/s and stagnation pressures ranging from 1 to 100 atm; (ii) the influence of shape and departure of heating environment predictions from those for a simple spherical geometry; (iii) assessment of thermal response models for silica subject to intense radiation; and (iv) results for porosity-driven gross fragmentation of meteors, idealized as a collection of smaller objects. Lessons learned from these simulations will be used to help understand the Chelyabinsk meteor entry [5] up to its first point of fragmentation.

References

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Comments:

Oral presentation with an accompanying written full-length paper.