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Validation of Knudsen numbers and flow regimes for well-characterized centimetre-sized meteoroids

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Abstract

For centimeter-sized meteoroids impacting the Earth's atmosphere, the formation of a vapour cap and eventually a shock wave creates a physical scenario that is still to be fully understood. This work analyses the flow regimes for such bodies and illustrates how infrasound information can provide relevant information in meteor science.

1. Introduction

In 1974 Revelle [5, 6] outlined a theory to study the weak shock that occurs after the decay of a highly non-linear strong shock wave created as a result of the meteoroid's passage through the atmosphere. The low frequency (<20 Hz) generated by a cylindrical shock wave [7] can be detected from ground detectors and eventually provide relevant information on the associated meteor phenomena (the optically detectable light production due to the meteoroid ablation [2]). This theory was later validated with a large meteoroid data set for which the infrasound information was linked to visual observations [8]. Additionally, the altitude of the meteor generated shock wave was constrained in [7] by finding the point along the meteor trajectory from which infrasound signal originated. Although this altitude is not diagnostic of the initial onset of the shock wave, it represents the earliest known point for which the shock wave is determined to exist.

In this work, we demonstrate that this information is valuable in extending our understanding of the meteor flow regimes of impacting meteoroids. Additionally, we show that the use of a flow regime scale that accounts for the physics of the event is more adequate than a simplistic general approach. A sample of 24 well constrained centimeter-sized events are taken from [8] to carry out our study. To our knowledge, this is the only well-documented and well-constrained set of such events to-date.

2. Flow regimes

When a centimeter-sized meteoroid enters the Earth's atmosphere at hypersonic velocities, the incoming atmospheric molecules ejects large number of meteoroid atoms. The accumulated number of particles in front of the meteoroid creates a vapour cap that acts as an "hydrodynamic shielding" [4] and reduces the number of high energy impacts. At lower altitudes, when the pressure of the vapour in the flow field surrounding the meteoroid significantly exceeds that of the surrounding atmosphere (at least two orders of magnitude), the vapour gas expands radially behind the shock envelope and as such, can be considered as a hydrodynamic flow [4]. In a simple sense, that creates a shock discontinuity where the pressure, density and temperature experiences large jumps. As a consequence, the mean free path behind the shock discontinuity changes and hence the flow regime shifts [9].

The flow regimes are classified according to the Knudsen number (Kn), which is a dimensionless parameter defined as the ratio between the mean free path of the gas molecules (λ) to a physical length of the body immersed in the gas (Kn=λ/L). In order to account for the mean free path of the reflected (evaporated) meteoroid atoms relative to the impinging particles, the reference frame in this study is set at the meteoroid surface [1]. Furthermore, we use two different flow regime classifications to understand the differences when including possible viscous effects in the shock layer (the region between the shock wave and the meteoroid surface). On one hand, the classification outlined by Tsien [10] includes the evolution of the Reynolds number to determine the meteoroid flow regime evolution. On the other, we consider the more general Knudsen scale that only accounts for the number of intermolecular collisions within a specific time.

3. Conclusions

Our results show that most of the meteoroids included in our sample are between slip-flow and the continuum flight regime conditions [3]. Despite some minor discrepancies, the results derived from the two classifications (Tsien's and general Knudsen scale) are quite similar. Furthermore, we analyse the effect of varying some initial assumptions made on the general physical parameters (e.g., bulk density, meteoroid surface temperature, negligible deceleration) that may slightly vary for each sample member, only to find minor discrepancies [3].

We note that the scale outlined by Tsien [10] accounts for those parameters that have the largest influence in the results (i.e., the meteoroid entry velocity, viscosity, etc.) as these are held in the *Re* number. This suggests that the use of the Tsien's scale is more appropriate for this kind of study. Finally, we compare our results to the results obtained in [4] for a Leonids meteoroid in order to validate our conclusions.

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References

[1] Bronshten, V.A.: D. Reidel Publishing Co., Netherlands p. 372, 1983.

[2] Ceplecha, Z. et al.: Space Sci., Rev. 84, pp. 327-471, 1998.

[3] Moreno-Ibáñez, M. et al.: ApJ, in revision, 2018.

[4] Popova, O. P. et al.: Earth Moon Planets, Vol. 82/83, pp. 109-128, 2000.

[5] ReVelle, D. O.: PhD thesis Univ. Michigan, 1974.

[6] ReVelle, D. O.: JGRE, Vol.81 (17), pp. 1217-1230, 1976.

[7] Silber, E. A., and Brown, P. G.: JASTP, Vol. 119, pp. 116-128, 2014.

[8] Silber, E. A. et al.: JGRE, Vol. 120, pp. 413-428, 2015.

[9] Silber, E.A. et al.: MNRAS, Vol. 469(2), pp. 1869-1882, 2017.

[10] Tsien, H. S.: *Aeronautic. Sci., Vol. 13(12), pp. 653-664, 1946.*