Absence of Wake in Faint Television Meteors

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Wake is the degree to which an instantaneous meteor image is spatially distributed. We used a MCP intensified SIT video detector preceded by a mechanical rotating shutter to search for wake in a sample of faint (down to +7.8 apparent magnitude), mainly sporadic meteors. The detailed analysis of 217 video frames (25 meteors) yielded only one meteor with statistically significant sustained wake. This absence of wake is consistent with earlier work (Robertson & Hawkes, 1992). The spatial resolution and dynamic range have been improved in the present study. We estimate that wake greater than approximately 200 m could have been detected by our observing system, provided that the intensity of wake illumination was at least 1/16 that of the main meteor luminosity. We interpret the absence of wake as indicating that most meteors of this size have already disintegrated into constituent grains prior to the beginning of intensive ablation, and that the mass distribution of constituent grains is fairly narrow (at most a factor of about 100 in mass).

Earth, Moon, and Planets **68**: 493-502, 1995.

Introduction

McCrosky (1958) pointed out that wake (spatial spread of the instantaneous light production region) was present in about one-third of the Super-Schmidt meteor records. Since wake was more prevalent in low velocity meteors it was argued that it was due to differential grain deceleration of dustball meteoroids which fragmented during atmospheric flight, and not the result of atomic excitation and decay processes (see e.g. Halliday, 1958). Since the length of the luminous trails of faint television meteors (Jones & Hawkes, 1975) and the general features of the dependence of height on magnitude (e.g. Hawkes et al., 1984) were generally consistent with a dustball model for these smaller meteoroids, it was natural to assume that wake would also be present in the fainter television meteors. However, in a preliminary study (Robertson & Hawkes, 1992) statistically significant wake was found in only 2 of the 27 faint image-intensified video meteors studied. In this paper we have improved the observational equipment and the analysis procedures in a second search for wake in faint meteors.

Equipment and Data Collection

The combined effects of persistence and meteor motion during the video frame integration time results in extensive apparent wake which totally masks real wake in normal image intensified video meteor systems. As in our previous work (Robertson & Hawkes, 1992) we employed a mechanical rotating shutter in front of the objective lens in order to reduce the impact of persistence and meteor motion. We used a 30 Hz Texas Instruments SY20001 synchronous AC motor coupled to a light 15 cm plastic two-holed circular shutter (see Shadbolt, 1993 for additional details). Using a photodiode and digital storage oscilloscope an effective exposure time of 5.45 ms was measured. In order to obtain sufficient sensitivity our earlier observations (Robertson & Hawkes , 1992) had utilised a microchannel plate (MCP) image intensifier lens coupled to a second MCP and a fibre-optically coupled charge injection device (CID) video camera. The result of two MCPs and a medium resolution CID resulted in rather poor spatial resolution. The system used in the present work employed a single MCP intensifier (Varo 3603-1 Mil. Spec.), lens coupled to a better resolution SIT video system (COHU 4652). The objective lens was a Minolta 50 mm focal length F/1.2. The final system was limited to $+7.8^{M}$ over a field of view of 22.5°x16.9°.

Each video frame was uniquely time-stamped by a Panasonic WJ810 time-date stamper, and the NTSC video data was then recorded on a Panasonic AG2510 VHS VCR. Data used in this analysis was collected over five different nights during May , 1992. The rotating shutter system reduced the effective meteor rate for the system from about 5 sporadic meteors per hour to approximately 1. A total of 33 meteor were recorded over 26^{h} 32^{m}. All data were collected at Sackville NB Canada (64° 21' 38" W; 45° 55' 30" N). A fixed observing direction of approximately azimuth 323° and elevation 66° was employed.

A RasterOps 24stv video digitisation board in a Macintosh IIcx microcomputer was used to digitise each video frame to 8-bit monochrome (256 grey levels). The digital image measurement and processing software NIH Image, developed and placed in the public domain by Wayne Rasband of the US National Institutes for Health, was used for all image analysis. Only 25 of the 33 meteors were suitable for analysis (excluded meteors being too faint to yield statistically significant intensity information). These 25 meteors ranged in apparent magnitude at maximum luminosity from $+2.8^{M}$ to $+4.8^{M}$. A total of 217 video frames were analysed for the present work.

Ignoring meteor motion and wake, we would expect the rotating shutter to produce two circular spots per video frame. Persistence causes spots from preceding video frames to be visible. Meteor motion and real wake should elongate each spot in the direction of motion, while detector blooming causes image enlargement in all directions.

The details of the wake search algorithm are provided by Shadbolt (1993), and are summarised below.

(i) Calculate the centroid of each meteor spot (each pixel was weighted according to the difference between its pixel intensity value and the mean local background intensity value).

(ii) Determine a "best fit" line for the region around this centroid, using those pixels with intensities statistically above the background level (again applying the same weighting procedure).

(iii) Measure (along the best fit line directions) from the centroid point to the edge of the image - this yields the apparent wake value.

(iv) Perform a similar measurement in a direction perpendicular to the best fit line - this yields the blooming value.

(v) Subtract the blooming value from the apparent wake in order to determine the corrected apparent wake.

(vi) Determine the meteor motion distance by multiplying the open duty cycle of the rotating shutter by the distance travelled between "spots" in the meteor image.

(vii) Subtract the meteor motion distance from the corrected apparent wake to obtain an estimate of the true wake value.

We further required that the best fit line of the image agree with the apparent direction of the motion of the meteor within two standard deviations (assuming that the wake is produced by trailing fragments along the line of motion), and that the wake be present on at least two sequential video frames[1] .

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[1] In North America the NTSC video standard means that each video frame corresponds to 1/30 s.

Results

The results of this research are simply stated: the vast majority of faint television meteors demonstrated no wake at all - a typical composite image being shown in Figure 1 (for meteor May 5 1992 04:47:42 UT). It can be seen that there is very little evidence of any luminosity at all between the roughly circular spots (the "shadows" are an artifact of the scanned video detector). Only one of the 25 meteors studied demonstrated statistically significant wake. This meteor (May 5 1992 02:49:46 UT) appeared to approach the camera within a few degrees of head-on, and was of long duration (45 video frames analysed). For this meteor most of

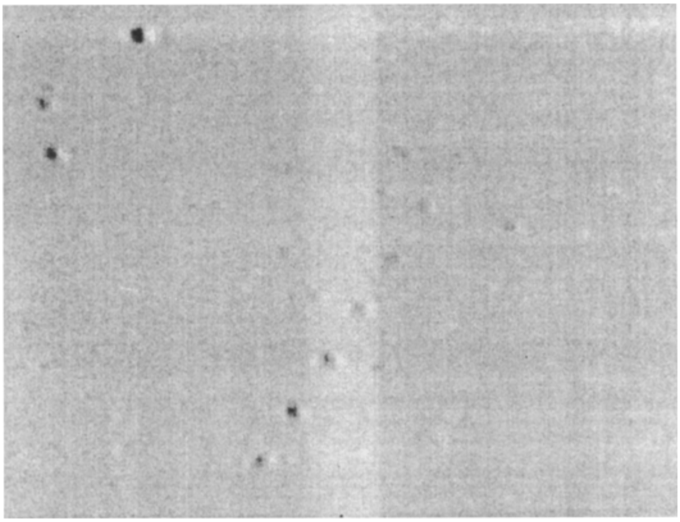

Figure 1

Typical rotating shutter microchannel plate (MCP) image intensifier - video detector images showing no significant wake. The meteor is a sporadic from May 5 1992 04:47:42 UT. This is a composite of 9 video frames (the dots going from top to bottom across the middle portion of the image at about a 45° angle). There is no obvious elongation along the line of motion, and hence no obvious wake in these images.

the frames with statistically significant wake were in the last one-quarter of the meteor trajectory. Since these were single station observations, it is not possible to specify the ablation heights. Robertson & Hawkes (1992) also found that the maximum wake (in those few cases when any wake was observed) occurred near the end of the trajectory.

Conclusions and Discussion

If we combine these results with our earlier work, it appears that less than 5% of faint sporadic meteors demonstrate statistically significant wake. When wake does occur, there is some indication that it is most pronounced in the latter stages of the meteor flight, and is probably more likely to occur in brighter meteors.

We will now consider the spatial and intensity resolution of our equipment. In the present study one pixel[2] corresponds to 0.074°. If one assumes a mean height of ablation of 95 km and the mean elevation angle of 66° (corresponding to a mean range of 104 km), and further assumes a mean projection factor of 0.7, each pixel will correspond (on average) to approximately 190 m spatial separation along the meteor trail. We therefore feel that wake in excess of about 200 m could have been detected by our system. In terms of intensity, the faintest meteors studied were about 3^M brighter than the limit of our system. Therefore fragments producing wake luminosity 1/16 the brightness of the main meteoroid could have been detected by our equipment, even in the case of the fainter meteoroids.

If one assumes that meteor wake is caused by differential aerodynamic lag of released fragments, one can fairly readily model the resulting lag (see e.g. Robertson & Hawkes, 1992). For demonstration purposes we present in Figure 2 results for

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[2] This is the size of the resolution elements in the original image. The actual "pixels" referred to in the work by Shadbolt (1993) are 1/5 this size, since they correspond to the digitally processed images which were expanded 5x using a bilinear interpolation operation in NIH Image.

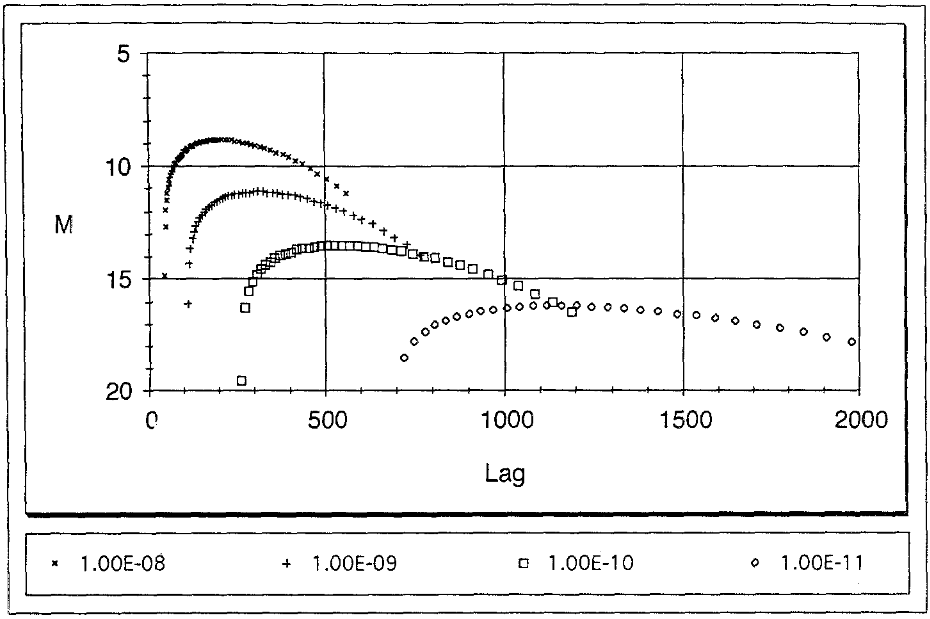

Figure 2
Plot of astronomical magnitude versus lag (in m) for grains ejected at a height of 120 km from a 30 km/s, cos z=0.7 meteor. A mean grain density of 1000 kg/m^3 is assumed. Results are shown for the four different grain mass (in kg) values indicated.

fragments with masses 1x10^{-8} to 1x10^{-11} kg, all with bulk density 1000 kg m^{-3}, released at 120 km height from a 30 km s^{-1}, cos z = 0.7 meteor. We plot apparent meteor magnitude versus lag[3]. On the plot each point represents a time interval of 0.01 s, however the different fragments reach the plotted magnitude range after different time intervals, so that the first point on the 1x10^{-11} kg plot

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[3] Lag is here defined as the difference between the position of a nondecelerated large main body and this fragment.

corresponds to the 7th point on the 1×10^{-10} kg plot, the 9th on the 1×10^{-9} kg plot and the 10th on the 1×10^{-8} kg plot. Simulations show that grains released below the height of normal ablation produce their luminosity over a very small height and time interval. Clearly a mix of luminosity from grains released at heights such as 120 km and grains released at meteor ablation heights would result in aerodynamic lag and wake significantly greater than the 200 m limit of our observational equipment.

According to the quantitative dustball ablation model of Hawkes and Jones (1975) meteors of the size studied here are composed of two components: fundamental grains held together by a second "glue" component. It is quite possible that this "glue" is a CHON coating on the grains of the type proposed by M. Greenberg and coworkers. The disintegration temperature of the "glue" is less than the boiling point of the grains, and depending on the size of the meteoroid disintegration into a cluster of grains prior to the onset of grain ablation is possible. Beech (1984,1986) and others have performed analyses which suggest that most meteors of the size studied by image intensified video equipment have already broken into clusters prior to the commencement of intensive grain evaporation.

It would appear that the absence of wake in most faint television meteors can only be explained in two ways: either these meteors do not fragment at all, or else they fragment into a cluster of grains prior to ablation heights, and this cluster has a fairly narrow size distribution. Given that the statistical trail lengths appear too short for nondisintegrating meteoroids (e.g. Jones & Hawkes, 1975) and that the light curves of faint meteors seem too irregular for single body ablation (Fleming, Hawkes & Jones, 1993), we prefer the cluster explanation. The absence of discernible wake sets a limit on the breadth of the grain mass distribution. For example, the data of Figure 2 suggests that a mixture of grains from 10^{-8} to 10^{-11}

kg would result in measurable wake. It would appear that most meteoroids have a fundamental fragment size distribution which is restricted to at most a factor of 100 in mass. Based upon our numerical simulations we suggest 10^{-8} to 10^{-10} kg as the most likely fragment mass distribution range. Simonenko (1968) obtained similar results from an investigation of meteor flare duration.

Further wake studies, perhaps employing electronically gated MCP intensifiers, higher resolution CCD video detectors, and longer focal length optics should be able to further restrict the fragment size distribution. Why meteors disintegrate into this comparatively narrow range of fragments is quite probably related to conditions present in the comet forming region of the early solar system, and these data therefore have considerable astronomical importance.

Acknowledgements

This work was supported by operating and equipment grants from the Natural Sciences and Engineering Research Council of Canada. One of the authors (LS) was supported by a Bell Junior Research Fellowship from Mount Allison University.

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