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# WAKE IN FAINT TELEVISION METEORS

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*The two component dustball model was used in numerical lag computation. Detached grain lag is typically less than 2 km, with expected wakes of a few hundred meters. True wake in television meteors is masked by apparent wake due to the combined effects of image persistence and blooming. To partially circumvent this problem, we modified a dual MCP intensified CID video system by addition of a rotating shutter to reduce the effective exposure time to about 2.0 ms. Preliminary observations showed that only 2 of 27 analyzed meteors displayed statistically significant wake.*

## INTRODUCTION

Wake is the degree to which an instantaneous meteor image is spatially distributed. The classic wake paper (McCrosky, 1958) pointed out that a large proportion (28%) of Super-Schmidt meteors showed significant luminosity in "off" portions of rotating shutter photographs. Since wake was more prevalent in low velocity meteors, he argued that wake was due to differential grain deceleration (lag), and not the result of atomic excitation and decay processes. The lag of grains from a fragmenting dustball was consistent with the emerging view of meteoroids as low density, structurally weak bodies which fragmented during flight (Jacchia, 1955), which in turn was in agreement with Whipple's "dirty snowball" cometary model (Whipple, 1950, 1951). Studies of meteor wake provide one method of determining the size distribution of meteoroid constituent grains. McCrosky (1958) suggested that grains of the order of $10^{-8}$ kg matched observational wake evidence, a value in agreement with flare analysis results (Smith, 1954; Simonenko, 1968a). Although image intensified video detectors are common in meteor observation (Hawkes & Jones, 1986), to our knowledge this is the first study of television meteor wake.

## NUMERICAL STUDY OF GRAIN LAG

We have previously performed numerical solutions of the coupled differential equations of meteoroid grain flight (Nicol et al., 1985; Fyfe & Hawkes, 1986). For this work we have added an equation specifying the lag of the grain, and have computed the luminous intensity. The rate of change of height, h, can be expressed as

$$\frac{dh}{dt} = -v\cos(z) \qquad (1)$$

where v is the instantaneous meteor speed and z the zenith angle. The meteoroid grain deceleration is

$$\frac{dv}{dt} = -\frac{\Gamma A v^2 \rho_a}{m^{1/3}\rho_m^{2/3}} + g \qquad (2)$$

with $\Gamma$ the drag coefficient, A the grain shape factor, $\rho_a$ the atmospheric density, m the instantaneous meteor mass, $\rho_m$ the grain bulk density and g the acceleration due to gravity. The rate of mass loss is given by

$$\frac{dm}{dt} = \frac{A m^{2/3}}{L \rho_m^{2/3}}\left[4\sigma\varepsilon\left(T_b^4 - T_a^4\right) - \frac{\Lambda \rho_a v^3}{2}\right] \qquad (3)$$

where L is the sum of the latent heats of vaporization and fusion, $\sigma$ the Stefan-Boltzman constant, $T_b$ the boiling point of the meteoroid material, $T_a$ the effective atmospheric temperature, $\varepsilon$ the emissivity and $\Lambda$ the heat transfer coefficient. We have considered thermal radiation, but, assuming very small grains, have ignored thermal heat capacity. If lag, l, is defined as the separation between a grain and an undecelerated parent meteoroid

$$\frac{dl}{dt} = v_\infty - v \qquad (4)$$

where $v_\infty$ is the initial speed. This definition of lag is reasonable for grains ejected from much larger parent bodies. If the luminous visual power is proportional to the rate of change of kinetic energy of ablated meteoric atoms, and the luminous efficiency factor varies linearly with speed, the grain luminosity will be

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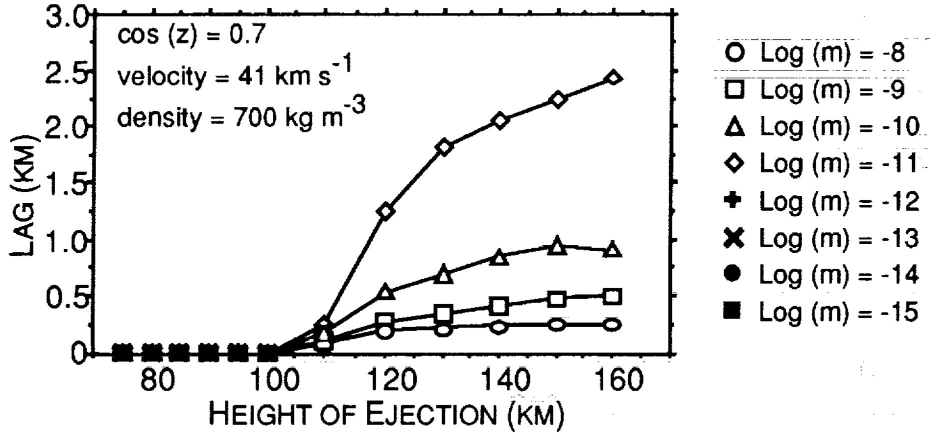
$$M = -2.5 \log\left\{ -\frac{\tau_o}{2} v^3 \frac{dm}{dt} \right\} \qquad (5)$$

We performed numerical integration of eqtns. (1) through (4), and then applied equation (5), using a fourth-order Runge-Kutta procedure with adaptive step size control (a slightly modified form of procedure RKQC in Press et al., 1986). A cubic polynomial fit between height and the logarithm of the atmospheric density (according to the U.S. Standard Atmosphere) was used. Constant values used were $A = 1.21$, $g = 9.60$, $\Gamma = 1.0$, $L = 6.0\times10^6$, $\Lambda = 1.0$, $\varepsilon = 1.0$, $T_a = 280$, $T_b = 2100$ and $\tau_o = 1.0\times10^{-10}$ (in all cases SI units). We performed 2304 numerical runs, corresponding to all combinations of the following values: cos z (0.4, 0.7, 1.0 ); preatmospheric velocity (15, 41, 60, 66 km $s^{-1}$); initial grain mass ($10^{-8}$, $10^{-9}$, $10^{-10}$, $10^{-11}$, $10^{-12}$, $10^{-13}$, $10^{-14}$, $10^{-15}$ kg); grain bulk density (700, 3500 kg $m^{-3}$); and ejection height (75, 80, 85, 90, 95, 100, 110, 120, 130, 140, 150, 160 km). Space does not permit presentation of the complete numerical results (see Robertson, 1990). Fig. 1 illustrates typical results for 41 km $s^{-1}$ velocity and cos(z) = 0.7. For the smallest grains, even the higher speeds will not produce significant ablation, and no lag is plotted. As expected, the lag increases as the grain mass or grain density decreases, since the smaller mass to surface area ratio results in more rapid deceleration. The lag increases with increasing height of ejection. The principal reason to carry out lag computations is not to confirm these predictable trends, but rather to determine the order of magnitude of the lag. According to the dustball model of Hawkes & Jones (1975) the composite meteoroid has two constituents, grains and a binding material of somewhat lower boiling point. For bright meteors grain release and grain ablation occur almost simultaneously. For faint meteors the grains will be released prior to grain ablation, and an essentially independent cluster of grains encounters the atmosphere. Wake could result from grains of uniform size released at different heights, or from grains of different



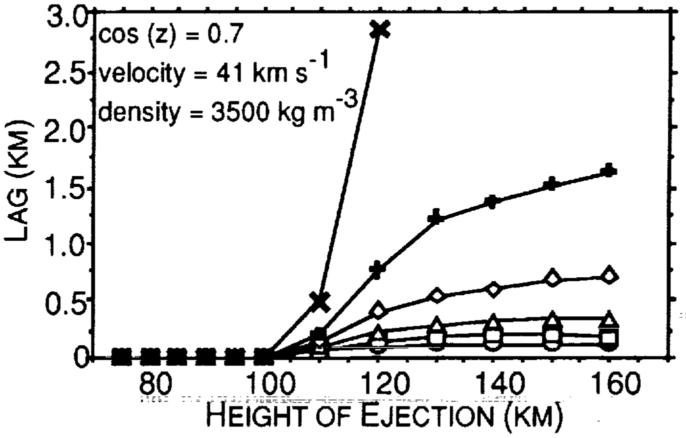


**Figure 1**

**Plot of lag at maximum luminosity versus mass of detached grains and height of grain ejection. The above plot is for a meteoroid density of 700 kg $m^{-3}$, while the plot on the right is for 3500 kg $m^{-3}$.**

sizes ejected at the same height. For example, Fig. 1 suggests that a mixture of grains of size $10^{-9}$ to $10^{-10}$ kg would lead to wake of approximately 250 m. If grain release occurs high in the atmosphere, and at a variety of heights, rather spectacular lags and associated wakes result. Grains of size $10^{-11}$ kg released over a range from 110 to 150 km would result in about a 2 km wake.

## OBSERVATIONAL EQUIPMENT

Interpretation will be most straightforward in the case of meteors small enough to have fragmented into a cluster of grains prior to the onset of intensive grain evaporation. Beech (1984, 1986) has applied techniques developed by Hapgood et al. (1982) to estimate the critical size, which he suggests may be -2 for Perseid meteors, -1 for Geminid meteors and +0.5 for Southern-Taurid meteors. However, there is considerable scatter in the data, and image intensified television systems should be used to achieve the required sensitivity with confidence. The problem with such systems is that the combined effects of persistence and meteor motion during the frame integration time results in extensive apparent wake which totally masks real wake. Blooming of bright images provides a further complication. The persistence problem can be reduced by making the effective image intensifier exposure short. The optimum way to accomplish this would be to employ an electronically gated image intensifier, but cost precluded our adoption of this approach. We chose instead to use a mechanical rotating shutter driven by a 30 Hz synchronous motor (to keep the shutter in phase with the line locked video camera). The shutter had two circular holes of radii 3.0 cm in an overall shutter of radius 15.0 cm, resulting in one exposure per video field (1/60 s), with an effective exposure time of about 2.0 ms. A block diagram of our observational equipment is shown in Fig. 2. The first microchannel plate (MCP) image intensifier was a Varo model 3603-1 (luminous gain 30,000). It was lens coupled to an ITT 4562 camera (a MCP fibre-optically coupled to a GE TN2505 CID video camera). The sensitivity was about $+7.5^M$ with a 135 mm/f3.5 objective lens (field of view 8.1° by 6.1°). The rotating shutter was clearly effective in reducing apparent wake due to image motion and persistence, with most frames indicating roughly circular meteor images.

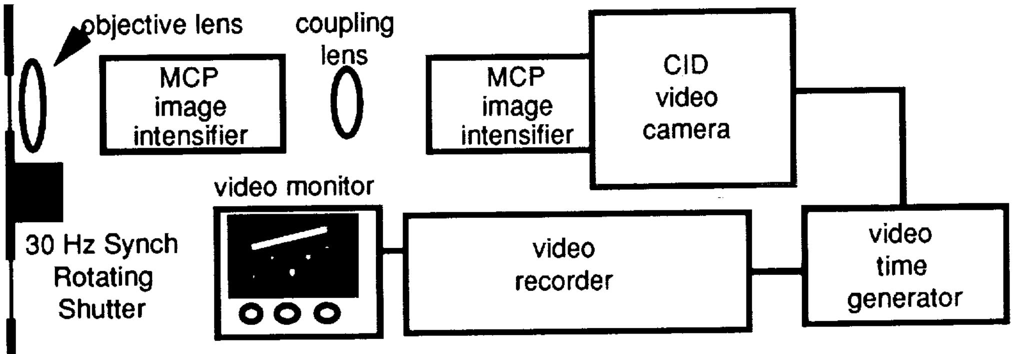


**Figure 2 Block Diagram of Observing Equipment**

## ANALYSIS AND RESULTS

Data were collected during 5 nights in Aug. and Sep. 1989 from Sackville, N.B., Canada (long. 64° 22' 24" W; lat. 45° 53' 35" N). A total of 27 meteors were analyzed from a $24^h$ $48^m$ observing period. Each video frame was digitized using an Oculus-200 video digitizer in an IBM XT {resolution 512x512 pixels, 7 bit (128 gray levels) depth}. If a meteor exhibits wake then the pixels contributing to the meteor's image should be noncircular with the best fit line through those pixels aligned with the meteor trajectory. After each video frame had been background corrected a linear regressional analysis was performed with every pixel weighted according to that pixel's luminous intensity. A meteor was only deemed to have wake if more than one of its images produced a slope in agreement (within the standard error) with the meteor trajectory. Of the 27 meteors studied, only 2 demonstrated statistically significant wake. To determine the size of the wake we started at the image centroid and moved backward in the direction of the trajectory until the pixel intensity was less than two standard deviations above the background noise. This apparent wake was then corrected for blooming and image motion during the

2.0 ms effective exposure. The maximum corrected wake was 30 pixels for one meteor, and 7 pixels for the other. In both cases the maximum wake point was near the end of the trajectory. A radiant-apparent speed check indicated that the two meteors were sporadic, and we can only estimate the statistically probable spatial dimension of the wake. At the elevation angle of 54°, assuming an ablation height of 95 km and 0.7 as a correction for the statistically probable trail orientation, the probable spatial dimensions of the wake at maximum are 780 m and 160 m.

## DISCUSSION

The failure to find significant lag in most of the meteors is surprising. One explanation would be that grains were all of approximately the same size, and were ejected at about the same height, so that each grain would lag by the same amount. Simonenko (1968b) found that the range of fundamental meteoroid grain sizes was quite limited. Another possibility would be that the grains were very large, in which case they would have small lags which might not be evident with the spatial resolution of our observing system. The origin of fainter meteors is generally assumed to be cometary, but some authors (Olsson-Steel, 1988) have recently suggested that the asteroid belt may be an important source for smaller meteoroids. This might mean that the structure of small meteoroids is more compact, and not a loose collection of grains. The boiling point of the glue might be very similar to that of the grains in which case there would be little time for lag. One should keep in mind that these results are based on a small number of meteors, and with an observing system limited in spatial and intensity resolution.

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