LA-UR- 97: 662

Title: **RADIATION FROM HARD OBJECTS**

Author(s): Gregory H. Canavan, DDP

Submitted to: For discussions outside the Laboratory

RECEIVED
MAY 05 1997
OSTI

Date: February 1997

MASTER

Los Alamos
NATIONAL LABORATORY

Form No. 836 R5
ST 2629 10/91

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

LA-UR--97-662

RADIATION FROM HARD OBJECTS

Gregory H. Canavan

The inference of the diameter of hard objects is insensitive to radiation efficiency. Deductions of radiation efficiency from observations are very sensitive—possibly overly so. Inferences of the initial velocity and trajectory vary similarly, and hence are comparably sensitive.

This not studies the sensitivity of the radiation signature from hard objects, i.e., ones that do not ablate. It reviews previous work briefly, derives the equations that exhibit the sensitivity of object size and speed to radiation efficiency, and assesses the sensitivity of inferred size and speed to likely variations in efficiency. It indicates the sensitivity of inferred parameters to the radiation efficiency for strong, non-ablating objects. The principal result is that inferences of object diameter are insensitive to radiation efficiency, although deductions of radiation efficiency from observations are very sensitive—possibly overly so. Inferences of the initial velocity vary similarly, and hence are comparably sensitive.

Estimates of radiation efficiency have ranged over two orders of magnitude. These results indicate that a 4-fold uncertainty in observations would be required to produce that range of values. They also indicate that in this approximation the fraction of the kinetic energy radiated by an object is approximately equal to the radiation efficiency, independent of the details of pulse length, altitude, and peak power. Thus, it is necessary to have additional information or to have an accurate estimate of radiation efficiency from without the model. Such an estimate can be produced by more thorough treatments of radiation. This note only provides a framework for assessing the accuracy they must attain to produce useful estimates of object parameters.

Review of earlier work. The kinematics and optical signatures of hard, strong objects entering the atmosphere are simple, because their high heat of vaporization prevents ablation and their great strength prevents break up into smaller pieces. The rate of deceleration of such an abject is given by

$$MdV/dt = -\rho CAV^2, \tag{1}$$

where $\rho(z)$ = air density at altitude z, A = cross-sectional area, V = speed, and C = meteor drag coefficient, which is ≈ 2 for Newtonian spheres. For hard, strong objects, area does not change, so A and M are constant, and it is possible to solve for V in an exponential atmosphere of scale height H as

$$V = V_0 e^{-H\rho/\beta\sin\theta} \tag{2}$$

MASTER

where $\beta = M/CA \approx \rho_a D$ is the ballistic coefficient of the incident object of density ρ_a and diameter D and θ is its angle of incidence with respect to the horizontal. Equation (2) uniquely relates V to z and also determines the radiated power

$$P = K\rho CAV^3 = KCAV_o{}^3\rho\, e^{-3H\rho/\beta\sin\theta}, \tag{3}$$

where K is approximately a constant and about a few percent. Thus, the radiated power is also a unique function of z. P can be differentiated with respect to ρ to find the density at which the radiated power is a maximum, which is

$$\rho_{maz} = \beta\sin\theta,/3H; \tag{4}$$

so the peak radiated power is

$$P_{max} = KCAV_o{}^3\rho_{max}\exp(-3H\rho max/\beta\sin\theta). \tag{5}$$

The altitude of peak radiation is

$$z_{maz} = H\ln(\rho_o 3H/\beta\sin\theta). \tag{6}$$

The width of the radiation pulse in altitude is $\approx 2H$ and in time is $\Delta t = kH/V_o$, where $m \approx 2$.

Parameter estimates. These result can be inverted to produce an estimates for the object size, speed, and angle of incidence, as discussed in an earlier note.[1] For the object diameter, that process produces the equation

$$D \approx [(9/2)^3\Delta t^3\rho_{max}{}^2P_{max}/K\rho_a{}^3]^{1/5}, \tag{7}$$

in terms of the object's radiation pulsewidth Δt, density of maximum radiation, and maximum power, which can be used to estimate D from measured quantities. D depends most strongly on the three measurements Δt, ρ_{max}, and P_{max} and the radiation model parameter K. The parametric variation of D with Δt, ρ_{max}, and P_{max} is studied in the earlier note. Of principal interest here is that D depends on the radiation efficiency only through $K^{1/5}$; thus, a precise value of K is not needed for an accurate estimate of D. Conversely, however, an accurate estimate of D is not necessarily an indication of the accuracy of the value of K used the data interpretation, as $K \propto D^5$. Thus, a 32-fold error in K would be necessary to make a factor of two error in object diameter, but a 2-fold error in the value of D could make a

This process also provides equations for the other quantities. The diameter, density, and angle of incidence equations can be inverted to infer the initial object velocity

$$V_o = m(2\rho_a D/3C)/3\Delta t\rho_{max}, \tag{8}$$

which is proportional to D. Thus, V_o is also weakly sensitive to K. The angle of incidence is determined by

$$\theta = \sin^{-1}(kH/V_o\Delta t), \tag{9}$$

which scales on V_o and hence K as $\sin^{-1}(1/K^{1/5})$. The scaling is strongest for low angles of incidence, i.e., approaches from the horizon; however, the geometry and density approximations used in this model are least accurate there.

Sensitivity. Figure 1 shows the inferred value of D from Eq. (7) as a function of the altitude at which the radiation is maximum for values of k from 0.01 to 1 for a peak power of 10^{11} watts and $\Delta t = 0.5$ s. The bottom curve is that exhibited for this power in the previous paper. The curves above it represent successive decreases of factors of 3 in k, which produces successive increases of factors of $1/3^{1/5} \approx 1.25$ increases in D as larger diameters are required to produce the given P_{max} at lower radiating efficiencies. The fraction of the hard object's energy radiated is roughly equal to k, because from Eq. (5)

$$P_{max} = KCAV_o{}^3\rho_{max}/e = KCAV_o{}^3\beta\sin\theta_r/3eH = KCAV_o{}^2\beta(V_o\sin\theta_r/H)/3e$$
$$= KCAV_o{}^2\rho_a D(k/\Delta t)/3e \approx (4KCk/3e)4\pi/3\rho_a(D/2)^3 V_o{}^2/2\Delta t \approx K\,E/\Delta t, \qquad (10)$$

where E is the initial kinetic energy of the object. Thus, in this approximation the fraction of the kinetic energy radiated by an object is approximately K, independent of the details of Δt, ρ_{max}, and P_{max}. The sensitivity of θ is somewhat less. Estimates of K have ranged from about 0.3% to 30% in the last century. Thus, these results indicate that about a 4-fold uncertainty in D would be required to produce this range of values.

Summary and conclusions. The discussion above indicates the sensitivity of inferred parameters to the radiation efficiency K for strong, non-ablating objects. The principal result is that inferences of D are insensitive to K, although deductions of K from observations of D are very sensitive—possibly overly so. Inferences of the initial velocity vary similarly, and hence are comparably sensitive to K. Estimates of K have ranged over two orders of magnitude. These results indicate that about a 4-fold uncertainty in observations of D would be required to produce this range of values. They also indicate that in this approximation the fraction of the kinetic energy radiated by an object is approximately K, independent of the details of Δt, ρ_{max}, and P_{max}. Thus, it is necessary to have additional information or to have an accurate estimate of K from without the model. Such an estimate can be produced by more thorough treatments of radiation. This note only provides a framework for assessing the accuracy they must attain to produce useful estimates of object parameters.

References

1. G. Canavan, "Deceleration and Radiation of Strong, Hard Asteroids During Atmospheric Impact," Los Alamos report La-UR-95-1477 rev, 1 February 1977.

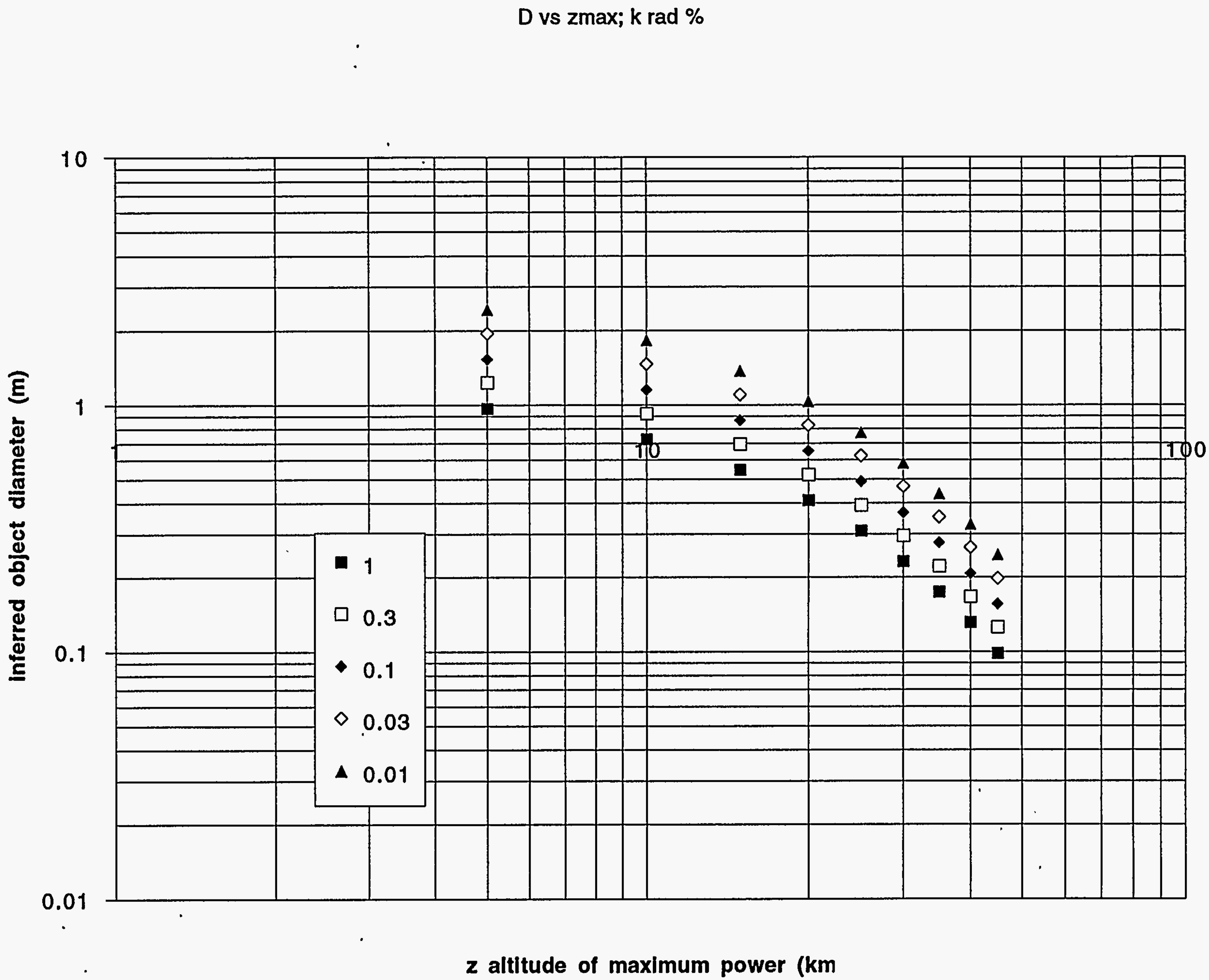

Fig. 1. Inferred object diameter as a function of altitude at which power reaches maximum for various radiation