An analysis of apparent slope data from Pugh et al.
And its bearing on the azimuth and entry angle of the bolide

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Abstract - An analysis of apparent slope data from Pugh *et al*. (this website), using the method described by Jenniskens *et al*. (1992), corroborates the solution for the trajectory and radiant direction obtained by Matson. The solution by Pugh *et al*. from a crossing lines of azimuth analysis, overestimates the azimuth direction and entry angle by at least 15 degrees in entry angle, and several degrees in azimuth. Their solution for the speed results in a strongly hyperbolic orbit, indicating their speed solution of 35 km/s is too fast. For the radiant position obtained by Pugh *et al*., the border between an elliptic and a hyperbolic orbit is well below 35 km/s, at 24.8 km/s.

Introduction

Pugh *et al*. (this website) present a very fine set of eyewitness observations of the 3 June 2004 fireball. In this contribution, their data will be used in an analytical method with focus on the change in apparent slope of the meteor trail as seen from different locations in a circle around the fireball. The approach needs an estimate of the apparent slope angle, along with the azimuth and altitude of the endpoint, for a set of observers. Ideally, these observers should be spread in a full circle around the fireball. The method does not need the geographic location of the observer. The method and the equations are described by Jenniskens *et al*. (1992), who used it for reconstructing the trajectory azimuth and entry angle of the Dutch Glanerbrug meteorite. The necessary data for the 3 June bolide were supplied by Pugh *et al*. (contribution to this website).

Method and equations

An observer exactly in line with the trajectory direction will see the meteor drop down vertically. An observer exactly perpendicular to the trajectory will see the meteor trail at an angle corresponding to the entry angle. Observers viewing the trail under an obligue angle to the trajectory, will see it under varying angles, depending on their radial position with regard to the trail (Jenniskens *et al*. 1992). For positions in a full 360 degree circle around the fireball, the variation of the slope behaves as a sinusoid, the exact shape of which depends on the observed celestial end altitude:

$$\mathrm{Tan}\varphi = [\ \sin\ (Az_0 - Az)]\ /\ [\cos h_0 * \tan H - \sin h_0 * \cos(az_0 - Az)] \qquad (1)$$

In which φ is the observed apparent slope of the trail, Az and H is the radiant position, and Az_0 and h_0 are the azimuth and celestial altitude of the endpoint as seen by the observer.

When values for the observed azimuth (x-axis) and apparent slope (y-axis) are plotted in a diagram, lines can be fitted that correspond to equation (1). Slope angles are measured with respect to the vertical, and a meteor moving “from left to right” gets a positive sign, while a meteor moving from “right to left” gets a negative sign.

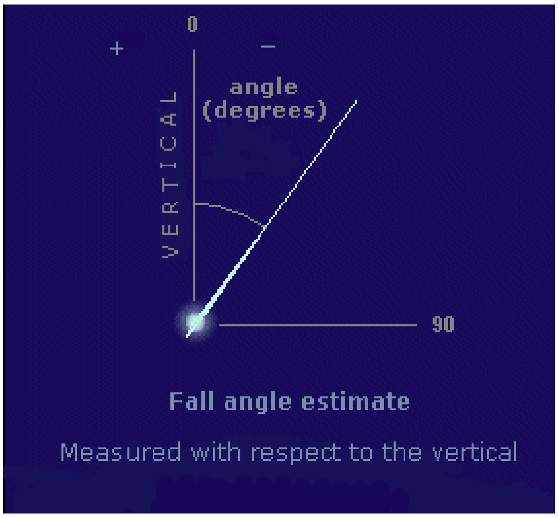


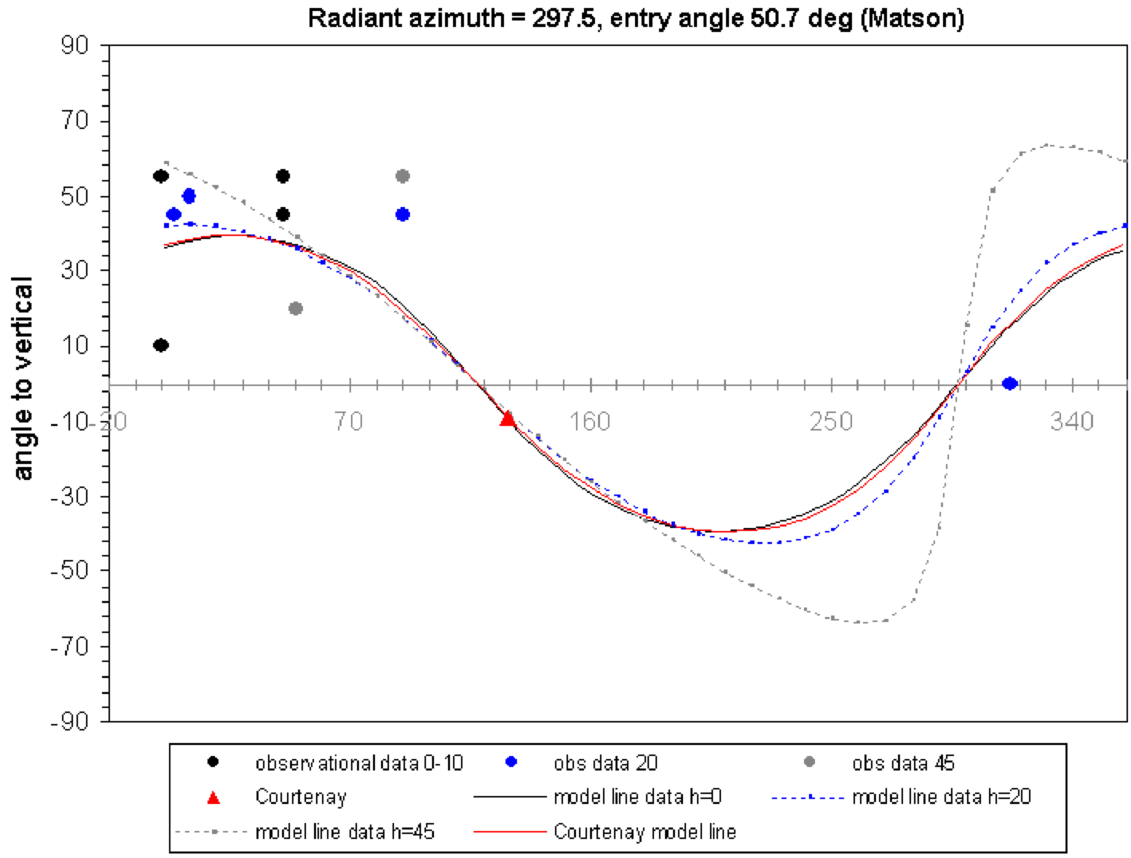
Table 1 from Pugh *et a*l. (this website) provides 11 datapoints of this type; while the video record from Courtenay provides a 12th datapoint (and evidently the most accurate of all). The slope as observed on the Courtenay video is -9.1 degrees, its end altitude is 5.1 degrees in azimuth 129.1 (from graphical data provided by Rob Matson).

In the diagrams (fig 2-4), the datapoints have been colour-coded into three classes, with model lines of matching colour: endpoint at 0-10 degrees altitude (black dots & black line); endpoint at 15-25 degrees (blue dots & line), and endpoint at 45 degrees (grey dots & line). The Courtenay datapoint is shown as a red triangle, with a matching red line. As this datapoint is derived from analysis of the position of the meteor on the video record, it has a much stronger weight in the discussion than the other (evidently widely scattering) datapoints.

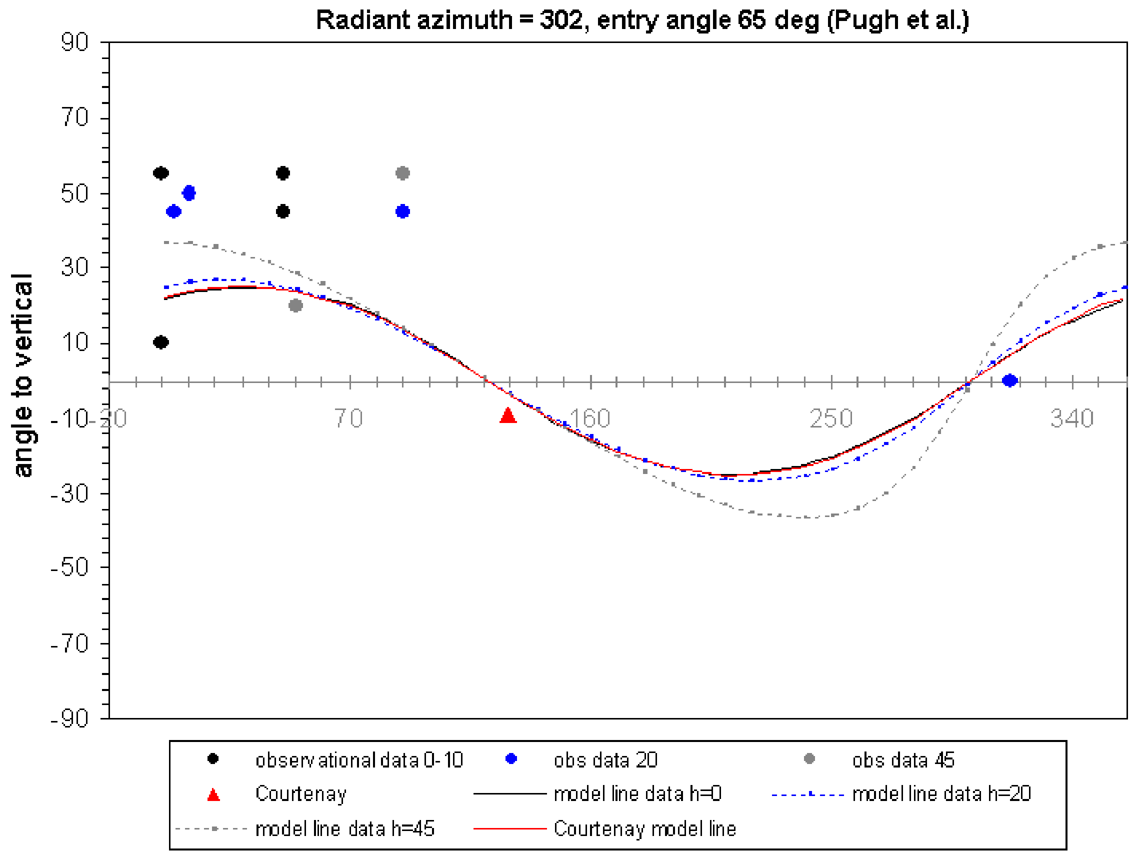
Comparison

The first two diagrams show the results for Matson's trajectory (entry azimuth from 297.5 degrees, entry angle 50.7 degrees) and for Pugh et al.'s trajectory (entry azimuth from 302 degrees, entry angle 65 degrees). As can be seen, for the trajectory of Matson, the datapoint for Courtenay falls almost dead-on the modelled line (the red line). By contrast, this is evidently not the case for the Pugh *et al.* trajectory, indicating that the azimuth estimate by Pugh *et a*l. is off by several degrees.

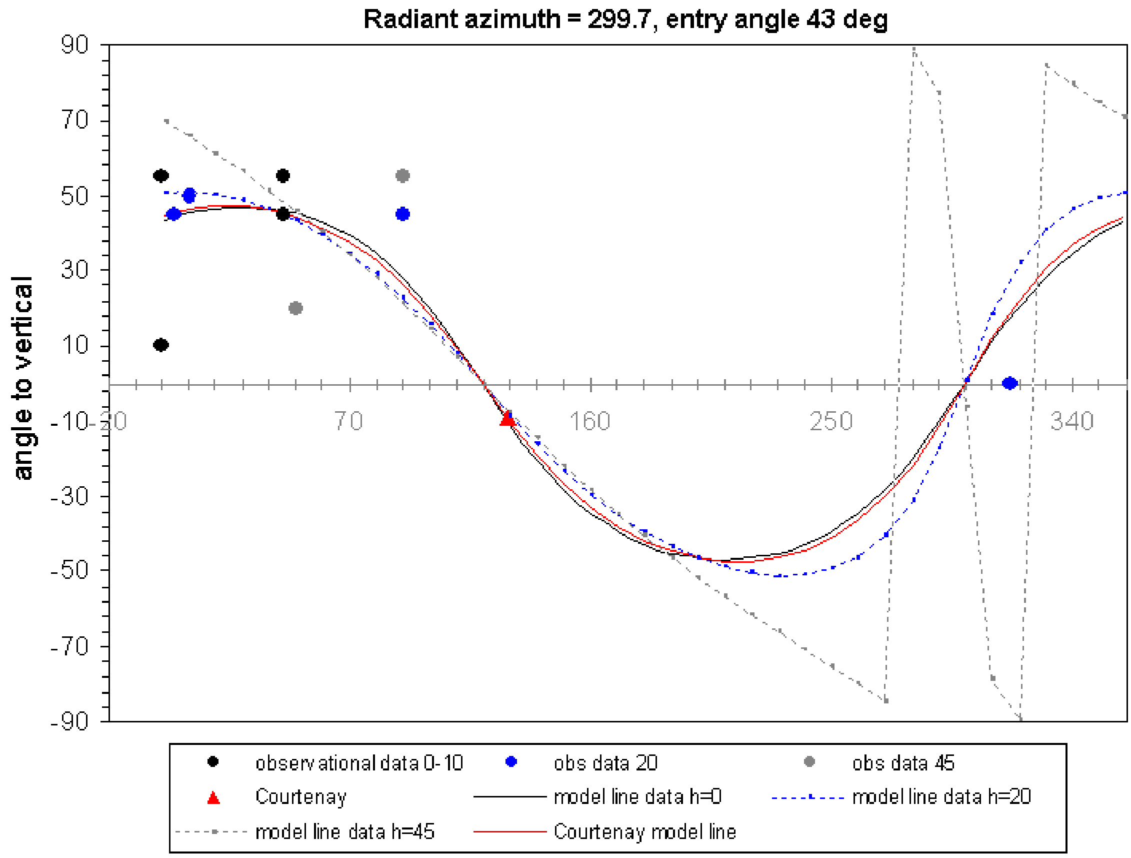
Moreover, the entry angle estimate of 65 degrees by Pugh *et al* does not match the data at all. Most of the datapoints are well above the modelled curves. This means the entry angle must have been clearly more shallow. In fact, even Matson's estimate of 51 degrees might be slightly too steep. An entry angle of 40-45 degrees would fit better, corresponding to an azimuth of 301-299 degrees.



Radiant azimuth = 297.5, entry angle 50.7 deg (Matson)
angle to vertical
90
70
50
30
10
-10
-30
-50
-70
-90
-20
70
160
250
340
observational data 0-10
obs data 20
obs data 45
Courtenay
model line data h=0
model line data h=20
model line data h=45
Courtenay model line



Radiant azimuth = 302, entry angle 65 deg (Pugh et al.)
angle to vertical
90
70
50
30
10
-10
-30
-50
-70
-90
-20
70
160
250
340
observational data 0-10
obs data 20
obs data 45
Courtenay
model line data h=0
model line data h=20
model line data h=45
Courtenay model line



Hyperbolic orbit

Another point of concern with the trajectory and speed results of Pugh *et al.*, is that their solution of radiant direction and speed (35 km/s), results in an orbit that is strongly hyperbolic (eccentricity = 1.877). The borderline between an elliptic orbit and an hyperbolic orbit, given their solution for the direction of the apparent radiant, is at 24.8 km/s, 10 km/s slower than their speed solution.
While a slightly hyperbolic solution, given the uncertainties could indicate an origin in a long period comet with *e* = ~0.9, a strongly hyperbolic solution indicates that the speed estimate is a clear overestimate.

Concluding remarks

An analysis of apparent slope data from Pugh *et al.*, corroborates the solution for the trajectory and radiant direction obtained by Matson. The solution by Pugh *et al.* from a crossing lines of azimuth analysis, overestimates the azimuth direction and entry angle by at least 15 degrees in entry angle, and several degrees in azimuth. Their solution for the speed results in a strongly hyperbolic orbit, indicating their speed solution of 35 km/s is too fast. For the radiant position obtained by Pugh et al., the border between an elliptic and an hyperbolic orbit is at 24.8 km/s.

Ackowledgement

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Reference:

- P. Jenniskens, J. Borovicka, H. Betlem, C. tere Kuile, F. Bettonvil & D. Heinlein: Orbits of meteorite producing fireballs. The Glanerbrug – a case study. *Astron. Astroph*. 255 (1992), 373-376.