The atmospheric model and challenges related to the drag law

The meteoroid body is flying through a planar atmosphere in our model. Air density is a function of the height. In our approximation the atmosphere is chemically homogeneous. Since the gas exhibits some kind of resistance against the moving bodies, the meteoroid will drag. This will cause a change of the velocity of the moving body, which can be calculated by introducing the related ‘drag force’. Under general conditions, it can be written as:

\[
\frac{dv}{dt} = -\frac{C_d}{m} \rho \cdot A \cdot v^2
\]

(3)

This scalar equation is seemingly very simple. As it is well known, the minus sign represents that this force is always reacting opposite direction to the temporary direction of the moving body, while the real index remembers us that the force is proportional with the ‘relative speed’ of the body, i.e relative to the surrounding medium. In a real atmosphere we have to have at least two realistic estimations about the wind speed at different heights. There are some public databases containing some information about this, at a rough time-, and spatial distribution, ra is the density of the air, as given interval or y which. By every day the real values are extrapolated. One can take it from real measurements (and interpolating between the known points), or one can use some one-dimensional or two-dimensional approximating calculation. The most generally used formula is the so-called ‘barometric approximation’, which is nevertheless running far from the real in situ measurements made by using high-altitude balloons:

\[
\frac{dv}{dt} = -\frac{\rho \cdot A \cdot v^2}{m} \left( \frac{1}{\rho_2} - \frac{1}{\rho_1} \right)
\]

(4)

Comparison of atmospheric models

While the different models and interpolated real measurements to the meteor body (considering by the the same height) from each others at low or very high altitudes, but at medium heights (between 20-80 km, which interval is most important for meteor flight) they exhibit large differences. As it can be seen in Figure 2, only the International Standard Atmosphere (1976) is representing well enough the real measurements. The plots referred as ECMWF and WAFO showing real data valid at the date of Easter Bolide of 2015, while “Strat-Pro” data were delivered by our own balloon experiment over Hungary in 2017.

The preliminary result shown in this poster was carried by using a one-dimensional power-formula atmospheric model (since the starting height of all studied cases remained below 33 km, thus the mentioned formula was an acceptable simplification).

The problem of the K factor (the so-called ‘drag coefficient’) in formula (3) introduces much larger uncertainty. Although one can find some efforts for theoretical derivation of its value, but most generally its tabulated values are based on laboratory experiments. In many previous dark flight calculations one can find the very simple substitution for K as a constant value around 0.4-0.5 (considering spherical or conical meteoroid body, since K is depending on the form of the moving body, why it is often cited as ‘form factor’). However, it is well-known nowadays, that K has a strong dependence on the relative speed and on the Reynolds number (which is characterizing the motion in the given medium). Some authors apply a simple dependency only on the Mach number (and what is also a problem: on rather narrow interval) or on the Reynolds-number. In reality: K depends on both factors. During our dark flight, meteoroid motion can hold big changes in the Mach- and Reynolds number (the concrete example of the 2015 Easter Bolide on Figures 3a, b, c). K formulas are from Vinnikov et al. 2016.

Effects of winds and some initial parameters

It is an interesting question, what is the effect of some initial parameters, and the real winds on the final place of the touchdown? For this, we show one of our results: the dark flight path in x-z plane. (The data is obtained from real measurements and interpolating between the known points). Figure 3a shows the ‘dark flight path’ resulting from our model calculations. It is and interesting question, what is the effect of some initial parameters, and the real winds on the final place of the touchdown?

The admission and test runs

The integration and test runs

The integration goes by the well-known and simple way: in each time step we take the i-th vector of the velocity, calculate the components of drag force by the drag law as by formula (3). After this, we can calculate the components of acceleration. In our approximation the temporary change of the meteor body’s position is found. Thus, the change of the cross section area of its body is not yet taken into account, as well as the possible fragmentation on the course of time. We consider the body as a constant mass and radius object.

The change of the velocity of the free-falling meteoroid body is given by:

\[
\Delta v = \int \frac{dv}{dt} = \int -\frac{C_d}{m} \rho \cdot A \cdot v^2 dt
\]

(5)

\[
\Delta v = \frac{1}{\rho_2} - \frac{1}{\rho_1}
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