Meteorite Finder Software

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Meteorite Finder is a software written in Matlab 2019b which computes the meteoroid's **dark flight** and delimits the **strewn field** on the ground where to go in search of meteorites. To work, Meteorite Finder needs at least an **atmospheric profile** computed for the starting point of the dark flight phase.

Introduction

Two conditions are necessary for the meteorites search on the ground: 1) Triangulate a sufficiently bright fireball that extinct at a final altitude of less than **about 30 km** with a **final speed under 3-4 km/s**. 2) Reconstruct the **dark flight** trajectory of the meteoroid as it falls towards the ground taking into account the **state of the atmosphere**, mainly **temperature**, **air density**, **wind intensity and direction** as a function of height. The motion equation in an **inertial reference system** describing the fall of a meteoroid with mass *m* in the dark flight phase is as follows:

$$m\vec{a}_m = \vec{F}_g + \vec{F}_d \qquad (1)$$

In Eq. (1) the first term represents the force of gravity, the second the drag force exerted by the air on the meteoroid. Explicating the two forces, we have:

$$\vec{F}_g = -GMm\frac{\vec{r}}{r^3} \qquad (2)$$

Where *G* is the gravitational constant, *M* is the Earth's mass and *r* the distance between the center of the Earth and the meteor. The **drag force** is given by:

$$\vec{F}_d = -\Gamma\rho_a vA\vec{v} = -\Gamma\rho_a\left|\vec{v}_m - \vec{W}\right|A\left(\vec{v}_m - \vec{W}\right) \qquad (3)$$

In this equation Γ is the **drag coefficient** (which depends weakly by the meteoroid's speed), ρ_a the air density, *A* the meteoroid cross section, $\boldsymbol{v}_m$ the meteoroid speed and $\boldsymbol{W}$ the wind speed. Putting Eq. (1), (2) and (3) together, the differential equation of motion of the meteoroid in the dark flight phase is:

$$m\frac{d\vec{v}_m}{dt} = -GMm\frac{\vec{r}}{r^3} - \Gamma\rho_a\left|\vec{v}_m - \vec{W}\right|A\left(\vec{v}_m - \vec{W}\right) \qquad (4)$$

This is a **non-linear differential equation** in vector form. Instead of using a reference system with the axes fixed in space, we can use a geocentric reference system, but with the axes rotating with the Earth's surface, which is the one in which the observer placed on the Earth's surface is located. In this case two **inertial forces** must be added: **Coriolis force** and the **centrifugal force**. The differential equation of motion in this **non-inertial system** becomes:

$$m\frac{d\vec{v}_m}{dt} = -GMm\frac{\vec{r}}{r^3} - \Gamma\rho_a\left|\vec{v}_m - \vec{W}\right|A\left(\vec{v}_m - \vec{W}\right) - 2\vec{\omega}\times\vec{v}_m - \vec{\omega}\times(\vec{\omega}\times\vec{r}) \qquad (5)$$

The first additional term is the Coriolis force, the second is the centrifugal force. In Eq. (5) $\boldsymbol{\omega}$ is the vector of the rotational speed of the Earth. By making explicit Eq. (5) for a **geocentric non-inertial Cartesian reference system** with z direction along Earth's rotation axis (so $\boldsymbol{\omega}$ is a vector with only the z component), x and y direction in the Equatorial plane, with x towards the Greenwich meridian, six first-order differential equations are obtained, three differential equations for the speed components and three for the position components. Solving these equations numerically, will provide the position and velocity of the meteoroid as it falls towards the ground and the intersection of the trajectory with the ground gives the strewn field position.

These are the equations that underlie **Meteorite Finder**, a software written in Matlab 2019b which computes the meteoroid's **dark flight** and delimits the **strewn field** on the ground. To work, Meteorite Finder needs an **atmospheric profile** computed for the starting point of the dark flight in which the following quantities are reported as a function of the distance from the ground:

Pressure (hPa), **wind u component** (m/s), **wind v component** (m/s), **temperature** (K), **relative humidity and height above ground** (m).

Of course, closer the different heights of the atmospheric profile are, smaller the uncertainty of the strewn field will be. For the initialization of the software it is necessary to edit the file "Settings.txt", providing all the necessary information, i.e. position, speed, inclination and direction of the trajectory of the meteoroid at the beginning of the dark flight. If desired, different Monte Carlo scenarios can be computed to estimate the uncertainty of the strewn field based on the uncertainty of the starting parameters. The compiled version of Meteorite Finder allows its use within a console without to install Matlab, but only the freely available libraries. As a first test, the default data can be used, relating to the fireball IT20200101 which led to the recovery of the "Cavezzo" meteorite by the PRISMA Project coordinated by INAF.

Meteorite Finder's Algorithm

1-Read "Settings.txt" file in main folder
2-Copy file "Settings.txt" in fireball's folder
3-Compute and save file "meteoroid_data.txt" in main folder to be read from ODEsystem.m script
4-Define working path and atmospheric profile location
5-Compute ECEF atmospheric profile from geopotential atmospheric profile and save ECEF "atmospheric_data.txt" in main folder to be read from ODEsystem.m script
6-Copy file "atmospheric_data.txt" in fireball's folder
7-Compute meteoroid starting speed in ECEF reference system
8-Compute meteoroid starting position in ECEF reference system
9-Define starting conditions vector: position and speed
10-Integrate 3D motion equations with Runge-Kutta 4th/5th order ODE solver (ODEsystem.m script)
11-Select physical solution (only points above Earth's surface)
12-Compute meteoroid speed module
13-Compute meteoroid heigh above surface, Lat and Long (WGS84)
14-Monte Carlo computation for uncertainty on Lat and Long of the nominal impact point (if selected in "Settings.txt")
15-Save the results in output file "Dark_flight_strewn_field.txt" (in fireball's folder)
16-Save dark flight trajectory in .kml files for Google Earth (in fireball's folder)
17-Save strewn field in .kml files for Google Earth (in fireball's folder)
18-Plot and save in fireball's folder dark flight and strewn field model results
19-End script

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