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Development of artificial meteor for observation of upper atmosphere

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A B S T R A C T

This study proposes a method for the observation of the upper atmosphere using an artificial meteor injected by a mass driver installed on a microsatellite. The mass driver injects a pill at a velocity of 200 m/s and deorbits it into the atmosphere. The emission of the pill can then be observed from the ground at the necessary time and location. This approach could contribute to a better understanding of the global environment as well as different aspects of astronomy and planetary science. To realize the proposed method, the required size and emission of the pill have to be determined. Therefore, we conducted flow-field simulations, spectroscopic estimations, and an experiment on an artificial meteor in the arc heater wind tunnel at the Institute of Space and Astronautical Science in the Japan Aerospace Exploration Agency (ISAS/JAXA). From the results, we confirmed that the light emission could be observed as a shooting star by the naked eye and thus verified the feasibility of the method.

1. Introduction

The development of microsatellites is actively being pursued at several universities and non-governmental organizations in the world, and a variety of related missions have been planned. In this paper, we propose a method for the observation of the upper atmosphere using an artificial meteor injected by a mass driver installed on a microsatellite.

The upper atmosphere is the region of the Earth's atmosphere that lies at approximately 100–1000 km above sea level. It significantly affects the global environment, and therefore it is necessary to understand its behavior so that more-precise atmospheric predictions can be realized through numerical models as well as practical observations. Such accurate predictions would be useful for efficient aircraft operation, lifetime evaluation of satellites, and assessment of space debris. Although the upper atmosphere has been observed by monitoring auroras and meteors using LiDAR and spectrometry, it is not possible to make observations at any location by these approaches. Moreover, balloons and sounding rockets cannot be used because of their altitude constraints. Thus, the upper atmosphere remains poorly understood.

To resolve this issue, we propose using a mass driver installed on a microsatellite to inject a pill into the atmosphere to act as an artificial meteor. In this method, the pill is injected at the required time and location on the Earth against the orbital velocity direction of the microsatellite. Because the speed of the pill will thus be less the orbital speed, its altitude will drop, and the friction with the air as

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Nomenclature

A	surface area of artificial meteor source (m^2)
c	light speed (m/s)
C_D	drag coefficient
D	magnitude of drag vector (N)
E	illuminance measured by illuminometer
E_g	Illuminance on ground when pill is emitted at altitude of 60 km (lx)
E_m	illuminance of m-th grade magnitude (lx)
E_n	illuminance of n-th grade magnitude (lx)
h	Planck constant
H	altitude (m)
k	Boltzmann constant
l	distance from light source to illuminometer (m)
M	mass of pill
m	visual magnitude
n	visual magnitude
r	orbital radius (m)
S	cross-sectional area (m^2)
T	temperature (K)
V	velocity of artificial meteor source
v_r	peripheral direction of velocity vector component (km/s)
v_θ	radial direction of velocity vector component (km/s)
α	direction of drag vector for radial speed component (rad)
θ	true anomaly (rad)
λ	wavelength (nm)
μ	gravitational constant (km^3/s^2)
ρ	air density (kg/m^3)

it re-enters the atmosphere will cause aerodynamic heating. LiDAR and spectrometers on the ground can then be utilized to observe the light emission of this artificial meteor, and the state such as wind velocity, temperature, and so on of the upper atmosphere at the location can be determined from the emission characteristics. Whereas the conventional observation by using natural meteor originally presumes the physical and chemical parameters around the values of state itself we would like to obtain, the observation with artificial meteor we proposed is able to determine the values without the presumption because of a known property of the pill.

We are now developing a satellite and the mass driver, and planning to a constellation of satellites being engaged in the observation of upper atmosphere, to enable a successive implement of the observation for two years, by taking a demand for the artificial meteors into consideration (Fig. 1).

By this method, observation of the upper atmosphere by light emission can be realized not only in the polar regions but at any point on the earth, and large amounts of data can be obtained at low cost. In addition, by utilizing meteor substances of known compositions in the pill, the fundamental processes of meteor phenomena including precise determination of velocity and trajectory can be studied.

To realize the proposed method, it is necessary to determine the optimal size of the pill and evaluate the emission time and intensity required for sufficient observations from the ground. Therefore, the objective of this research was to confirm the feasibility of this mission by estimating the emission intensity.

2. Simulation of light emission

The pill injected from the mass driver emits light as a result of the aerodynamic heating due to friction with the atmosphere. The characteristics of the light emission depend on the plasma radiation of the airflow around the shock wave, the spectra of the atoms and molecules in the upper atmosphere, and the blackbody radiation of the pill itself.

2.1. Orbit computation

First, we calculated the trajectory of the pill injected from the microsatellite and analyzed the flow field around the pill to estimate the radiation heating by the plasma. Then, we determined the visual magnitude of the emission combined with the blackbody radiation.

The artificial meteor is injected against the orbital velocity direction of the microsatellite in order to decrease its speed and put it on an elliptical orbit with the apogee at the injection point. When the injection speed of the pill is sufficiently large, the perigee becomes closer to the Earth than the atmosphere, and the pill re-enters the atmosphere while its velocity decreases further because of atmospheric drag.

For the calculation of the trajectory of the pill, we adopted the parameters listed in Table 1 [1].

The formulas used in the trajectory calculation are given below:

$$\dot{r} = v_r \tag{1}$$

$$\dot{v_r} = \frac{v_\theta^2}{r} - \frac{\mu}{r^2} - \frac{D}{M}\sin\alpha \tag{2}$$

$$\dot{v_\theta} = -\frac{v_r v_\theta}{r} - \frac{D}{M}\cos\alpha \tag{3}$$

$$\dot{\theta} = \frac{v_\theta}{r} \tag{4}$$

$$D = \frac{1}{2}C_D \rho V^2 S \tag{5}$$

The calculated trajectory of the pill is shown in Fig. 2, its velocity is shown in Fig. 3, and its flight characteristics at the altitude of 60 km, where it emits light similar to a shooting star, are presented in Table 2.

From the calculations, it was determined that the speed of the pill increases as it approaches the perigee, and the air drag due to friction is largest near the altitude of 50 km, where the perigee of the elliptical orbit of the pill becomes smaller than the radius of the Earth. If the pill does not