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CALCULATION OF REAL METEORIC LUMINESCENCE

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Abstract. Earlier, it was considered in the literature that luminosity of a body at its movement in the atmosphere with large speed is defined only by radiation of vapor of a body material, arising owing to evaporation of its surface. The integral from luminosity long time was used as a unique way of definition of extra-atmospheric mass of meteoric body. On the other hand, the mass of a meteoric body characterizes height and intensity of its braking in the atmosphere. In a number of works the essential divergence of masses received by these two ways was marked. In the paper, other treatment of luminosity of high-speed object in the atmosphere, not connected with its evaporation, is resulted.

1. BASIC FEATURES OF THE MODEL

We consider volume *W* of hot gas, inside of which there is a solid body with a surface **Σ**. The point of observation *N* is outside of the volume. Following assumptions are accepted.

1) Gas in the volume is in local thermodynamic equilibrium with known absorption coefficient κ_ν, which changes inside *W*.
2) The surface of a body has constant temperature T_Σ.
3) The degree of blackness of a surface is equal to unit.
4) The space between point *N* and volume *W* is filled by cold gas which completely passes radiation in a range [ν_1, ν_2] also absorbs radiation on other frequencies.

Under these conditions, a radiation flux **q** from volume of hot gas *W* and a surface of a body Σ in the point of observation *N* is given by formulas [1]:

$$q = \int_{\nu_1}^{\nu_2} \int_{\Omega} I_\nu \, \Omega \, d\Omega \, d\nu \,, \tag{1}$$

$$I_\nu = \int_{s_0}^{s_1} \kappa_\nu B_\nu \exp\left(- \int_{s'}^{s_1} \kappa_\nu ds'' \right) ds' + I_{\nu 0} \exp\left(- \int_{s_0}^{s_1} \kappa_\nu ds'' \right).$$

Here I_ν is the intensity of radiation depending on a direction of a beam, B_ν is Planck's function, $I_{\nu 0}$ is the intensity of radiation of border inside volume W.

At ground and satellite observations of bodies movement in the atmosphere, practically always, the size of area of a luminescence l is much less than distance L up to a point of observation N. Then the source of a luminescence is almost a dot light source. Expression for q becomes considerably simpler. We shall substitute expression for I_ν under an integral. We shall pass from integration on a solid angle to integration on part of the surface of the shone volume Σ_w^+, turned to the observer. We receive following expression for a stream of radiant energy q in the given spectral interval $[\nu_1, \nu_2]$:

$$q = \frac{1}{L^2}\int_{\nu_1}^{\nu_2}\left[\int_{W^+} \kappa_\nu I_{\nu p} \exp\left(-\int_{s'}^{s_1} \kappa_\nu ds''\right) dW + \int_{\Sigma_W^+} I_{\nu 0} \exp\left(-\int_{s'}^{s_1} \kappa_\nu ds''\right) d\sigma_n\right] d\nu . \quad (2)$$

Here W^+ is a part of volume W, visible from point N.

2. SCHEME OF THE FLOW PAST BODY

In this section, sites of fireballs trajectories in the Earth's atmosphere, on which the flow past body occurs in a range of fluid dynamics, are considered. Certainly, for a substantiation of the model applicability, it is necessary to have even the minimal data on characteristics of the meteoric body. It is possible to receive these data only as a result of correct interpretation of shone sector of the trajectory. Finds and the analysis of a meteorite after falling considerably raise reliability of these data.

A removed observer can perceive three basic sources of a meteor radiation:

1) Radiation of atmospheric gas in the shock layer about a body.
2) Radiation of vapor of a body material or other products of destruction.
3) Radiation of a body surface.

Here the first and third light sources are considered only. At a flow past body in a range of fluid dynamics, temperature of vapor is appreciable below than temperature of the compressed gas behind a strong head shock wave. The temperature of the body surface also is low. However, the form of a spectrum of a solid body in visible area absolutely other, than the form of a spectrum of vapor.

The following elementary form of the flow region is accepted. The meteoric body is considered spherical with radius R. The area of a wake behind the body is replaced with the impenetrable cylinder of radius R. Fields of pressure and temperatures for calculation of optical characteristics are defined as follows. At the beginning, the flow about sphere down to its middle section is calculated. The flow of the cylinder blunted on sphere further is calculated. At last, parameters of gas in the wake are considered equal to their values on external border of the wake, taken of the previous calculation.

3. OPTICAL CHARACTERISTICS OF THE RADIATING MEDIA

The site of a spectrum forming the image on a photographic plate is considered. The analysis of data of work [2] shows that the most probable interval of frequencies in observations is the following: [ν = 18500 – 26300 cm^{-1}]

Simple estimations due to tables of optical characteristics of air [3] show that optical thickness τ of the shock layer in a frontal part of a body in this range of frequencies is very small. So, for the fireball Lost City the greatest value τ in the bottom part of its trajectory does not exceed 0.01. Increase τ up to values of the order 1 is possible only for very large meteoroids as great pressure of gas in a shock layer is impossible because of destruction. Therefore in calculations the assumption about an optically thin shock layer is accepted. It simplifies the formula (2), which becomes

$$q = \frac{1}{L^2}\int_{\nu_1}^{\nu_2}\left[\int_{W^+}\kappa_\nu I_{\nu p}\,dW + \int_{\Sigma^+} I_{\nu 0}\,d\sigma_n\right]d\nu . \tag{3}$$

Here unlike (2) the second composed is calculated already by integration on a visible part of the body surface Σ^+ (instead of on Σ_w^+) as inside of volume *W* radiation is not absorbed.

4. LUMINESCENCE OF HOT GAS AREA

Calculations of a luminescence of the perturbed flow region about sphere in the assumptions described above are fulfilled.
Let's copy the formula (3), having transferred integration on frequency under a sign on integration on volume and surface. We shall receive

$$q = \frac{1}{L^2}\left[\int_{W^+} G(r)\,dw + \int_{\Sigma^+} G(s)\,d\sigma_W\right] \quad G(s) = \int_{\nu_1}^{\nu_2} I_{\nu 0}\,d\nu . \tag{4}$$

Considering that the radiating volume has the form of the body of rotation extended along axis *Oz*, it is convenient to copy (4) in a following kind:

$$q = \frac{1}{L^2}\int_{s_0}^{l}\int_{\sigma(z)} G(r)\,d\sigma\,dz , \tag{5}$$

having united in one integral the contribution of internal points of volume and points of the body surface Σ^+. Function

$$F(z) = \int_{\sigma(z)} G(r)\,d\sigma \tag{6}$$

gives a certain notion about the contribution of various sites of the perturbed flow region about sphere to the full radiation flux. Value $F(z)dz$ is equal to a radiation flux from cylindrical volume with the area of the basis $\sigma(z)$ and height dz. For $0 \le z \le 2R$ this value comprises radiation of a surface Σ^+ which in resulted below examples is calculated as radiation of absolutely black body with constant temperature T_Σ.

It is shown that the greatest contribution to the radiation flux gives a shock layer on a forward part of sphere. In the field of the middle section, function *F (z)* quickly decreases and remains small in the wake. Predictably, the contribution of the body surface is insignificant.

5. LIGHT POWER OF A METEOR

Intensity of a meteor is convenient to describe by a full light power

$$I = \int_S q \, d s \, , \tag{7}$$

where *S* is a sphere of radius *L* with the center in the light source. Neglecting the shadow region, i.e. including emission of light identical in all directions, we shall receive

$$I = I_W + I_\Sigma = 4\pi \int_W G(r) dw + 4\pi \int_\Sigma G(s) d\sigma_W \, , \tag{8}$$

where *W* and Σ are the full volume of the perturbed flow, and full body surface.

Regular calculations of light power of the radiating volume I_W were fulfilled. The value I_W is determined as a function of the body radius, its speed and density of the atmosphere at height of flight. The received results are approximated by following expression:

$$I_W = 5.84 \cdot 10^{11} R^3 (V_\infty / 10)^{12.6} \rho_\infty^{1.69} \, , \tag{9}$$

where I_W is defined in watts, *R* is in meters, V_∞ is in km/s, ρ_∞ is in kg/m^3. The formula (9) can be used in following ranges of parameters: $R \in [0.01, 1]$, $V_\infty \in [8, 18]$, $\rho_\infty \in [8.10^{-2}, 2.10^{-5}]$.

The formula (9) was used for comparison with observable luminosity of the Lost City fireball [2]. Satisfactory conformity of calculations and observations, mainly for the bottom part of the trajectory is shown. Distinction of data in the top part of the trajectory arises owing to the assumption of equilibrium flow in the shock layer about body and in a trace behind it.

6. REFERENCES

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