NEW METHOD FOR ENTRY DYNAMICS DETERMINATION UPON OBSERVATIONS

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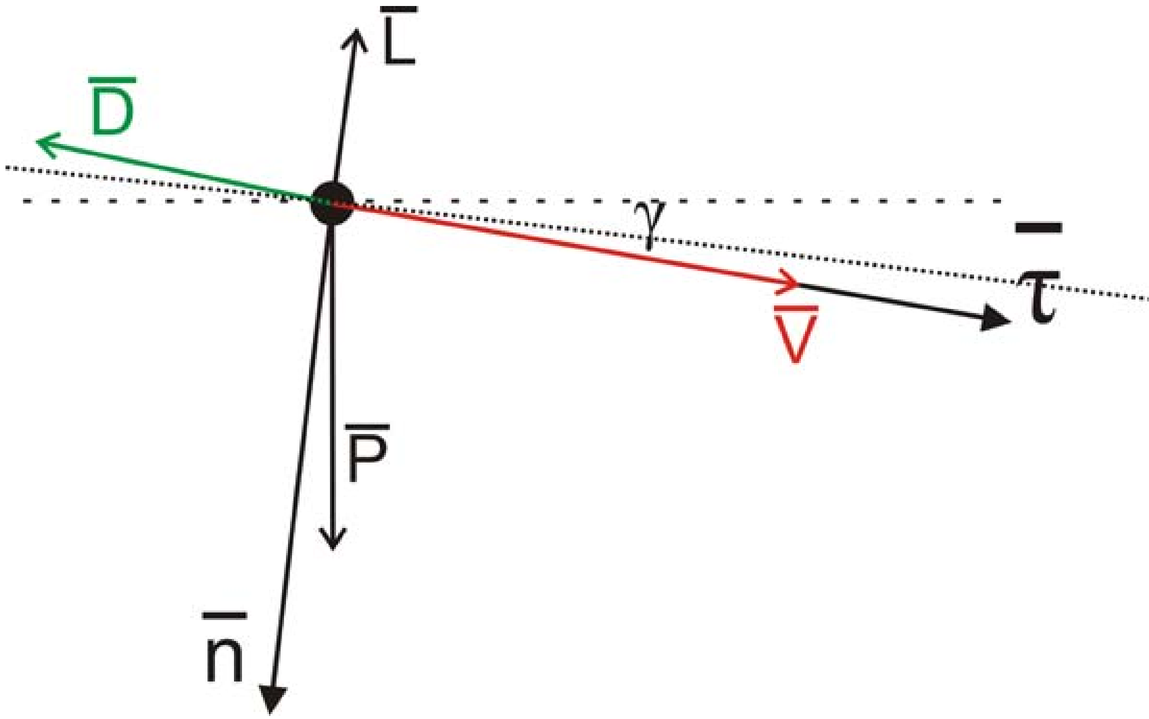
Equations of motion



Motion equations

$$M\frac{dV}{dt} = -D + P\sin\gamma$$

$$MV\frac{d\gamma}{dt} = P\cos\gamma - \frac{MV^2}{R}\cos\gamma - L$$

$$\frac{dh}{dt} = -V\sin\gamma$$

Mass changing equation

$$H*\frac{dM}{dt} = -\frac{1}{2}c_h\rho_a V^3 S$$

Aerodynamic forces

$$D = \frac{1}{2}c_d\rho_a V^2 S$$

$$L = \frac{1}{2}c_L\rho_a V^2 S$$

Basic parameters and assumptions

- $m = M/M_e$; M_e – the mass upon entrance into the atmosphere;
- $v = V/V_e$; V_e – the velocity upon entrance into the atmosphere;
- $y = h/h_0$; h_0 – the altitude of the homogeneous atmosphere;
- $s = S/S_e$; S_e – is the midsection upon entrance into the atmosphere;
- $\rho=\rho_a/\rho_0$; ρ0 – the gas density ρ0 at sea level;
- c_d – the aerobraking factor;
- c_L – the lift coefficient;
- c_h – the heat-exchange coefficient;
- H* – the effective destruction enthalpy;
- the trajectory angle γ is constant;
- c_L - unknown;
- velocity is more important neither weight;
- $s = m^{\mu}$, $\mu = \text{const}$;
- $\rho = \exp(-y)$;

Path equations

$$m\frac{dv}{dy} = \frac{1}{2}c_d \frac{\rho_0 h_0 S_e}{M_e}\frac{\rho v s}{\sin\gamma} \qquad \frac{dm}{dy} = \frac{1}{2}c_h \frac{\rho_0 h_0 S_e}{M_e}\frac{V_e^2}{H^*}\frac{\rho v^2 s}{\sin\gamma}$$

$y = \infty$: $v = 1$, $m = 1$

After symboling

$$m\frac{dv}{dy} = \alpha\rho\, vs \qquad \frac{dm}{dy} = \frac{2}{1-\mu}\alpha\beta\rho v^2 s$$

$$s = m^{\mu} \qquad \rho = \exp(-y)$$

Non-dimensional parameters

$$\alpha = \frac{1}{2} c_d \frac{\rho_0 h_0 S_e}{M_e \sin\gamma}, \quad \beta = (1-\mu)\frac{c_h V_e^2}{2 c_d H^*}.$$

α characterizes the aerobraking efficiency, since it is proportional to the ratio of the mass of the atmospheric column along the trajectory, which has the cross section S_e, to the body's mass.

β is proportional to the ratio of the fraction of the kinetic energy of the unit body's mass arriving at the body in the form of heat to the effective evaporation enthalpy.

Solution of the path equations

$$m = \exp\left(-\beta(1-v^2)/(1-\mu)\right)$$

$$y = \ln\alpha + \beta - \ln\frac{\Delta}{2}$$

$$\Delta = \overline{\mathrm{E}}\mathrm{i}(\beta) - \overline{\mathrm{E}}\mathrm{i}(\beta v^2), \quad \overline{\mathrm{E}}\mathrm{i}(x) = \int_{-\infty}^{x} \frac{e^z dz}{z}$$

Depends on 2 non-dimensional parameters

Mass computation

$$M_e = \left(\frac{1}{2} c_d \frac{\rho_0 h_0}{\alpha \sin\gamma} \frac{A_e}{\rho_T^{2/3}} \right)^3$$

Mass depends on ballistic coefficient.

We have to determine α to calculate fireball’s mass.

Least squares method

Using the least squares method, we determine the parameters α and β for which approximate trajectory best describes the observed data.

$$2\alpha \exp\left(-y\right) - \Delta \cdot \exp(-\beta) = 0 \qquad \text{trajectory}$$

The desired parameters α and β are determined by the values for which the minimum of the expression is attained

$$Q_4(\alpha,\beta) = \sum_{i=1}^{n} (F_i(y_i, v_i, \alpha, \beta))^2,$$

$$F_i(y_i, v_i, \alpha, \beta) = 2\alpha \exp\left(-y_i\right) - \Delta_i \exp(-\beta), \quad \Delta_i = \overline{\mathrm{Ei}}(\beta) - \overline{\mathrm{Ei}}(\beta v_i{}^2)$$

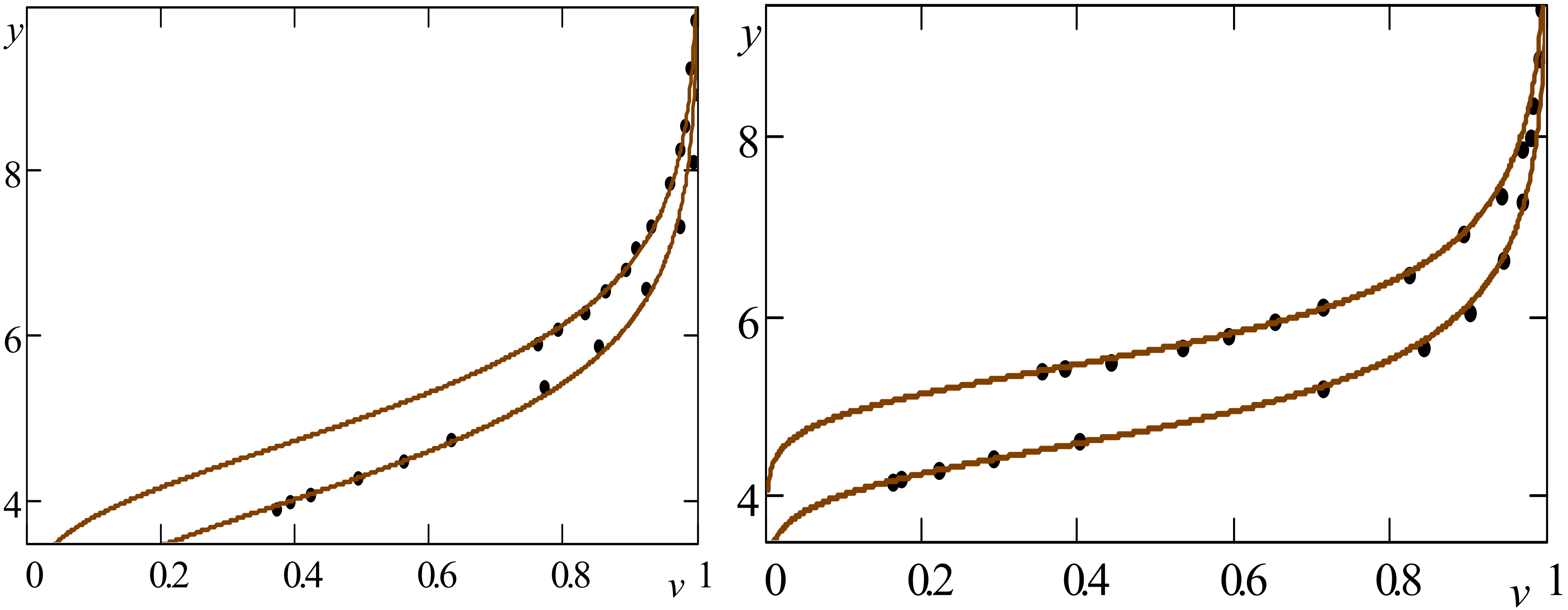
$$\alpha = \frac{\sum_{i=1}^{n} e^{-\beta - y_i} \cdot \Delta_i}{2\sum_{i=1}^{n} e^{-2y_i}} \qquad \Delta_i = -2\ln v_i + \sum_{k=1}^{\infty} \frac{\beta^k}{k \cdot k!}(1 - v_i^{2k})$$

$$f(\beta) = \sum_{i=1}^{n} \left[\left(\Delta_i \left(\sum_{i=1}^{n} \exp(-2y_i) \right) - \left(\sum_{i=1}^{n} \Delta_i \exp(-y_i) \right) \exp(-y_i) \right) \cdot (\Delta_i - (\Delta_i)'_\beta) \right] = 0$$

Dynamic parameters

MORP	V_e, km/c	α	β	$10^2 \cdot \sigma$, c^2/km^2
169	22,9	50,52	1,575	0,601
189	14,5	34,47	0,757	0,720
195	25,2	35,22	1,486	0,468
223	27,1	18,33	1,809	0,493
331	13,3	37,94	0,598	0,676
687	16,7	42,83	0,534	0,383
840	23,6	22,35	1,766	0,634
888	25,5	31,85	1,171	0,360

Computation of motion



We use the parameters α and β for which approximate trajectory best describes the observed data.

Extra-atmospheric masses

MORP	V_e, км/с	sinγ	M_e, kg	MI, kg	M_{ph}, kg
169	22.9	0.34	6.12	12	12
189	14.5	0.39	12.66	9.1	8.1
195	25.2	0.59	3.31	7.1	7
223	27.1	0.33	141.68	240	232
331	13.3	0.48	4.89	10	7.6
687	16.7	0.34	9.89	4.8	1.6
840	23.6	0.75	6.3	11	11
888	25.5	0.61	4.12	4.6	4.3

Conclusions

- Method for determination dynamic parameters was shown.
- Dynamic parameters were calculated.
- Masses of meteor bodies were calculated.
- Comparison of the masses was done .