A STYDY OF ABLATION ON A RE-ENTRY VEHICLE

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Abstract - The movement of vehicles in the dense layers of an atmosphere can be accompanied by intensive thermo – chemical destruction of their heat – shielding covering and sharp increase of destroyed and carried away material of covering amount. Intensive burning of the heat – shielding covering results in change of the initial form of the vehicle. It influences the aerodynamic characteristics of the vehicle, magnitude and distribution of thermal flows on its surface. Thus during research of the vehicle control in the atmosphere it is necessary to take into account effects of the heat – shielding covering of the vehicle burning.

Key – words: - Heat-shielding covering, Ablation of mass, Methods, Atmosphere, Spacecraft.

1. Introduction.

Note that in destruction of the heat – shielding material there are certain processes taking place in complex interrelation. The processes are: the blocking of convective flow caused by covering evaporation; shielding the radiant flow by absorbtion of radiation by products of decomposition on passage through burning layer; transfer and accumulation of heat at heat – shielding covering material. A full list of these processes even in research of the simplest configurations of e vehicle is very difficult problem and requires the numerical solution of the joint equations of energy, dynamics, chemical, kinematics and other relations. The method of account of the changed form of vehicle parameters and heat – shielding covering mass ablation is proposed in this work. The simplifying assumptions are used as basis in this method.

1. The level of a total thermal flow q_Σ is given as a dependence of density of the atmosphere ρ, velocity v, temperature T, on coordinates of point on surface of vehicle and vehicle geometry, in each point of a surface of vehicle.
2. The transfer of any infinitesimal element of the surface of vehicle due to heat – shielding material of covering burning for infinitesimal interval of time *dt* takes place in normal direction *n* to this element.
3. The speed ablation of the heat – shielding covering mass for unit area of surface of vehicle is proportional to the heat – shielding covering effective enthalpy η_{ef} [1]:

$$\frac{dm}{dt} = \frac{q_\Sigma}{\eta_{ef}}. \qquad (1)$$

The characteristics of the heat – shielding material (the density ρ_{hsc} and effective enthalpy η_{ef}) remain constant during process of ablation of vehicle mass, or are described as functions of parameters of incident flow, coordinates point of vehicle surface and its initial form geometry.

2. Assumptions and simplifications

With view of the assumptions and simplifications it is not always possible to make the universal equations for ablation mass account for the vehicle of any configuration.

For example, we shall consider the vehicle with spherical blunt – shaped cone with ground cutting (fig. 1):

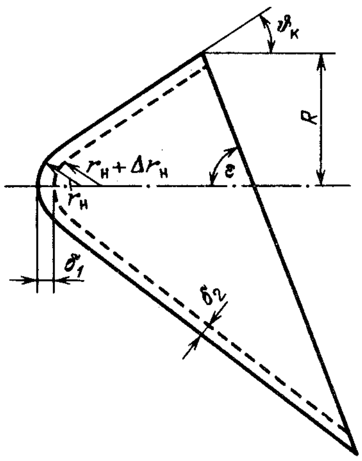

fig. 1.

The control of such vehicle is carried out by change of its roll angle on constant zero balance of attack angle. It allows to consider the flow process around nose part of the vehicle as axisymmetrical. The exact account of mass ablation, even for so easy configuration at above simplifying assumptions is difficult. Therefore we shall enter some more assumptions for the vehicle of this form:

- thickness of the carried away layers of heat – shielding covering materials for critical point δ_1 and on a lateral conic surface δ_2 are proportional:

$\delta_2=\delta_1 \kappa \cdot \sin\vartheta_\kappa$, (2)

where $\kappa<1$ – constant factor, ϑ_κ – the halt- angle of cone.

- the half angle of cone ϑ_κ and inclination of bottom cutting ε stay constant in this process; here the nose part of surface of vehicle remains spherical, and its radius varies so that the point of interface of sphere and a cone have no break.

In view of stated, we shall write down the equation for radius of bluntness in the critical point of nose part $r_н$, depending on thickness of burning layer δ1:

$$\Delta r_н = \frac{\sin\vartheta_\kappa}{1-\sin\vartheta_\kappa}(1-\kappa)\delta_1(\mathrm{q}_\Sigma), \qquad (3)$$

where qΣ – total amount of thermal flows.

In result the equation for change of mass of vehicle looks like:

$$\frac{dm}{dt}=\rho_{hsc}\frac{\mathrm{dU}}{dt}, \qquad (4)$$

where ρ_{hsc} – density of a heat – shielding covering material, U – the volume of vehicle, m – mass of vehicle.

3. Technique of account

From fig.1 it is visible, that volume of the vehicle is defined as function of parameters ε, ϑ_κ, $r_н$, R:

$$U= U(\varepsilon, \vartheta_\kappa, r_н, R). \qquad (5)$$

Taking the listed assumptions and relations (1-3) and (5) it is possible to rewrite equation (4) as:

$$\frac{dm}{dt}=-\frac{\dot{q}_\Sigma}{\eta_{ef}}F(\varepsilon,\vartheta_\kappa,r_н,R),$$

$$\frac{dr_н}{dt}=\frac{\dot{q}_\Sigma}{\rho_{hsc}\eta_{ef}}\cdot\frac{\sin\vartheta_\kappa}{1-\sin\vartheta_\kappa}(1-\kappa),$$

$$\frac{dR}{dt}=-\frac{\dot{q}_\Sigma}{\rho_{hsc}\eta_{ef}}\kappa\cdot tg\vartheta_\kappa,$$

(6)

$$F=-\frac{dU}{d\delta_1}=\pi\left[\begin{array}{l} R^2\left(\frac{tg\varepsilon+tg\vartheta_\kappa}{tg\varepsilon-tg\vartheta_\kappa}\right)^{3/2}\kappa \\ +r_н^2(1-\sin\vartheta_\kappa)(1-\kappa)\end{array}\right]. \qquad (7)$$

where F – derivative of volume change as complex function of moving surface at ablation of heat–shielding covering mass.

Here the q_Σ is defined as sum of convective and radiating thermal flows

$$q_\Sigma=q_\kappa+q_p, \qquad (8)$$

where formulas for calculation of q_κ and q_p are the following [2]

$$q_\kappa=\frac{1{,}291\cdot10^5}{\sqrt{r_н}}\sqrt{\frac{\rho}{\rho_0}}\left(\frac{V}{V_0}\right)^{3.25}, \qquad (9)$$

$$q_p=3{,}035\cdot10^7 r_н\left(\frac{\rho}{\rho_0}\right)^{1,3}\left(\frac{V}{V_0}\right)^8. \qquad (10)$$

So, with the formulas (6-10) it is possible to calculate amount of carried away vehicle's mass and change of its form in burning process of heat – shielding covering during braking in the atmosphere.

4. The simplified formulas

The simple approximate relations for estimation of carried away mass of spacecraft heat-shielding cover can be useful at realization of preliminary engineering calculations. The weight of heat-shielding loss of all the spacecraft surface can be determined from the differential equation.

$$\frac{dm}{dt} = \int_{S_П} \frac{q_\Sigma}{\eta_{эфф}} dS_П, \qquad (11)$$

Using the spacecraft mass as an independent variable taking into account equations in a stagnation point of spacecraft for a convective heat flow and radiation heat flow we shall receive the following expression for a speed of spacecraft mass ablation.

$$\frac{dm}{m} = \frac{1}{\eta_{эфф}}\left(1{,}31 \cdot 10^2 r_н^{-0{,}5} e^{0{,}5\lambda h} \overline{V}^{1{,}25} + 3{,}07 \cdot 10^4 r_н e^{-0{,}3\lambda h} \overline{V}^6\right) d\overline{V}, \qquad (12)$$

where $\overline{V} = V / V_{кр}$

it was supposed, that the atmosphere is isothermal, i.e. it has the exponential relation of density ρ altitude h at obtaining the relationship (12):

$$\rho = \rho_0 e^{-\lambda h}.$$

If the profile of the flight altitude velocity *h(V)* and change of radius bluntness in a stagnation point r_H *(V)* along spacecraft flight trajectory are known then the relation (12) can be used for estimation of weight losses of spacecraft heat-shielding cover. In the constant altitude flight segments *(*$h=h_1$*)* the radius r_H can be taken as constant value *(*$r_H=r_1$*)*, then the relationship (12) is integrated as follows:

$$\frac{m_o - m_к}{m_o} = 1 - \exp\left\{-\frac{1}{\eta_{эфф}}\left[58{,}22 r_1^{-0{,}5} e^{0{,}5\lambda h_1} \left(\overline{V}_{h_1}^{2{,}25} - \overline{V}_0^{2{,}25}\right) + 4{,}4 \cdot 10^3 r_1 e^{-0{,}3\lambda h_1}\left(\overline{V}_{h_1}^{7} - \overline{V}_0^{7}\right)\right]\right\}, \qquad (13)$$

where m_0 and m_K are the initial and final value of mass.

References

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