
**HIGH TEMPERATURE APPARATURES AND STRUCTURES**

**Force Loads on Space Vehicles during Landing under Conditions of Martian Dust Storm**

G. M. Arutyunyan

Central Research Institute of Mechanical Engineering, Korolev, Moscow oblast, Russia

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**Abstract**—Force loads on space vehicles during landing (and take-off) under conditions of Martian “dust storm” are investigated. Formulas are suggested for the calculation of arising loads on the object, including both the pressure of the gas component and the impacts of solid (or liquid) particles of the mixture.

**INTRODUCTION**

The atmosphere of the planet Mars under conditions of “Martian storms” is a binary or dispersed mixture of carbon dioxide CO₂ (95%) with the adiabatic exponent $\gamma = 1.67$ and solid particles of silicon dioxide SiO₂. The initial atmospheric pressure in the vicinity of the surface is $p_1 = 0.007$ bar = 700 Pa.

Patterns of sub- and supersonic flow of a homogeneous gas past a body have the form [1] shown in Figs. 1 and 2.

In the case of the heterogeneous mixture of gas and particles being treated, the pattern of flow past a body will be one-temperature and one-velocity, provided the following respective relations are valid:

$$\frac{a_1 c r^2}{V_1 \chi''} \ll l, \quad \frac{a_1 r^2}{V_1 \eta} \ll l,$$

where $l$ is the characteristic dimension of the body subjected to flow, $a_1$ is the velocity of sound in the initial mixture, $\chi''$ is the kinematic viscosity of the gas component, $\eta$ is the thermal conductivity of the particles, $r$ is the macroparticle size, $V_1$ is the specific volume of macroparticles, and $c$ is their specific heat.

**VELOCITY OF SOUND IN DISPERSED GAS**

The one-temperature pattern of the components of the binary mixture treated by us implies that we must use the latter one of two types of sound velocity, namely, “adiabatically adiabatic” and adiabatically isothermal”, given in the monograph [2], i.e.,

$$a_0 = -[(1 - x)V_1 + x V_2] \left\{-x \left( \frac{\partial V_2}{\partial p} \right)_T \frac{T}{(1 - x)c + x c_p} \right\}^{\frac{1}{2}}, \quad \text{(2)}$$

where $V_2$ is the specific volume of the gas component of the mixture, and $x$ is the mass content of gas.

We substitute the expressions

$$\left( \frac{\partial V_2}{\partial p} \right)_T = \frac{(c_p - c_v)T}{p^2}, \quad \left( \frac{\partial V_2}{\partial T} \right)_p = \frac{c_p - c_v}{p} \quad \text{(3)}$$

into formula (2) for $a_0$ to derive

**Fig. 1.** Pattern of subsonic flow past a body, $M_1 < 1.$
The parameter $a_0$ is provided by SiO$_2$.

Proceeding from formula (4), we will have

$$a_1 = \frac{(1 - x)V_1 + x(c_p - c_f)T_1}{V_1}$$

for the velocity of sound in region 1 of dispersed flow incident on the object.

Here, $p_1$ and $T_1$ denote the pressure and temperature in the initial mixture, and $c_p$ and $c_f$ denote the specific heat of the gas component at constant pressure and volume, respectively.

One can readily see that asymptotic relations follow from Eq. (5). At $x \to 1$, as was to be expected, we derive the Rayleigh formula for the velocity of sound in a homogeneous gas,

$$a_1 \to \frac{R}{\mu}$$

and, at $x \to 0$, for the velocity of sound in an incompressible (solid or liquid) medium; the first component of the dispersed gas being treated $a_1 \to \infty$ is in fact such a medium.

LOADS UNDER CONDITIONS OF SUBSONIC FLOW PAST A BODY

It is known [1] that, in the case of a homogeneous gas, the load under conditions of subsonic flow past a body is described by the relation

$$p_0 = p_1\left(1 + \frac{\gamma}{2} M_1^2 \right)^{\frac{\gamma}{\gamma - 1} - 1} + \frac{(1 - x)v^2}{V_1}$$

where $a_1$ must be determined by formula (5), and $\gamma'$, as is shown in [2], must be calculated by the formula

$$\gamma' = \frac{(1 - x)c + xc_f}{(1 - x)c + xc_p}$$

As a result, we derive, for $p_0$,

$$p_0 = p_1\left(1 + \frac{\gamma' - 1}{2M_1^2} \right)^{\gamma' - 1} + \frac{(1 - x)v^2}{V_1}$$

Figure 3 gives the results of calculations by formula (10) of $p_0$ as a function of $v$ (for different values of the parameter $x$) for normal conditions of the Martian atmosphere ($p_1 = 0.007$ bar, $T_1 = 215$ K).

One can see that the values of $p_0$ monotonically increase with $v$. As was already mentioned, the condensed phase is provided by SiO$_2$.

One can also see that, at $x = 1$ and $x = 0.95$, the respective curves $p(v)$ almost coincide while, at $x = 0.5$ and $x = 0.2$ (such anomalous states are quite feasible locally in the process of a “storm”), a significant difference is observed.

Figure 4 gives for comparison the results of calculations of $p_0$ as a function of $v$ for normal conditions of the Earth atmosphere ($p_1 = 1$ bar, $T_1 = 293$ K). One can see that, for the same values of the incident flow velocity, the loads under Martian conditions are several orders lower than those under terrestrial conditions.

Figure 5 gives the values of $p_0$ as a function of the content $x$ of the gas component in the Martian atmos-