Application of Special Mechanical Devices to Adapt the Descent from the Conditions of Mars to the Conditions of the Earth

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***Abstract*— The article proposes to use a special mechanical device that allows a soft landing of the landing vehicle (LV) on the planet's surface. This device is an inflatable braking device (IBD), which is deployed in an extra-atmospheric flight area. This device provides a passive stabilization of the descent vehicle. The landing vehicle with the inflatable braking device moves in the atmosphere of the planet, having a small twist around the longitudinal axis. The advantage of an inflatable braking device over traditional non-rigid braking devices - parachutes is that it can be used throughout all stages of descent, starting from hypersonic speeds and ending with subsonic ones. Such technical proposals are implemented in the MetNet project and its subsequent RITD project using the system of input, descent and landing (EDLS) [1].**

***Index Terms*—landing vehicle, inflatable braking device, movement in the atmosphere, numerical simulation**

I. Introduction

One of the most important stages of space flight is the final step - landing a spacecraft on the surface of the planet. The difficulty lies in the fact that it is necessary to reduce the speed with huge values during re-entry to the permissible values when landing on the planet's surface. Another important limitation is the limit weight and geometrical parameters of the spacecraft.

Thus, one possibility to perform braking of the spacecraft is the use of inflatable braking devices. One of such projects, which are used inflatable braking devices is MetNet project and its continuation RITD project.

In previous authors papers [2], [3] and [4] has been considered method of calculating the descent of the spacecraft in the atmosphere in different conditions and describes the results obtained in the study of motion landing vehicles in the planet's atmosphere. The paper [4] is devoted to describing RITD -project and is the result of a joint project team. Common methods of designing such devices as set forth in [5] and the special case considered in [6]. In paper [7], a similar descent vehicle is considered.

The scheme of the landing vehicle is shown in Fig. 1.

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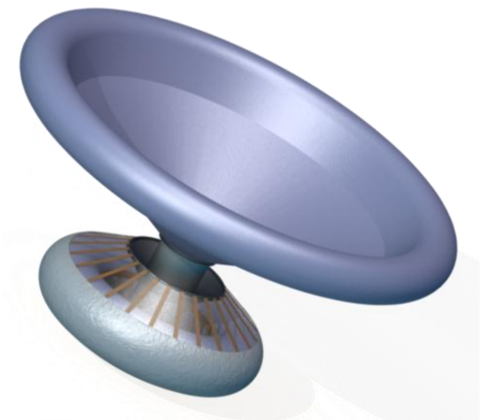

Figure 1. Exterior view of landing vehicle with deployed inflatable devices

II. Modelling

A. Analysis of the Effect of the IBD Deformation on the Dynamics of the LV Angular Motion in the Planet's Atmosphere

Application of the developed method [3] evaluating the influence of the IBD non-rigidity on the angular motion dynamics will be considered by the example of small LV destined to descend into the atmosphere. LV is an axisymmetric unit with two types of ballutes: primary inflatable braking device (PIBD) of conic type used for braking the LV after entering the atmosphere down to the altitude of a few kilometers, and additional inflatable braking device (AIBD) of conic type used in the final stage of descent. Outward appearance of the LV with PIBD is presented in Fig. 1.

B. Main Stages The Analysis Of The Dynamics Of Motion

Preview

The motion landing vehicle is considered as a rigid body, excluding the effect of deformation inflatable braking device.

Main

Analysis of the effect of deformation inflatable braking device on the dynamics of angular motion landing vehicle to the planet's atmosphere:

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1. Assessing the impact of the deformation of the main inflatable braking device on the dynamics of angular motion of landing vehicle in the upper atmosphere of the planet.
2. Assessing the impact of the deformation inflatable braking device on the dynamics of angular motion landing vehicle with the main inflatable braking device at resonance.
3. Assessing the impact of the deformation inflatable braking device on the dynamics of angular motion of landing vehicle with additional inflatable braking device on the destination, subsonic trajectory.

Parameters of the LV with the deployed PIBD entry into the atmosphere:

V –velocity of entry into the atmosphere; Θ – angle of slope of the velocity vector to local horizon; h – altitude; ω_x – the LV angular velocity about longitudinal axis; α_s – spatial angle of attack.

Let us first consider the motion parameters landing vehicle as a solid body, excluding the effect of deformation of braking device. On Figure 2, Figure 3, Figure 4 and Figure 5 presents graphs of velocity head, angular velocity relative to the longitudinal axis of the landing vehicle, the resonant frequency (ω_{rez}), lateral load q_s and spatial angle of attack α_s (ALFp) of flight time.

Under the resonance frequency is the value closest in meaning to the natural frequency of transverse vibrations, which is determined by the following formula:

$$\omega_{rez} = \sqrt{\frac{sl\left|m_z^{\alpha}\right|q}{I_j - I_x}} \tag{1}$$

where: $I_j = I_z$ or $I_j = I_y$

In this paper, we consider the resonant frequency for the case $I_j = I_z$.

On Figure 2 the graphs of the angular velocity ω_x (OMx) of landing vehicle rotation about the longitudinal axis and the resonant frequency ω_{rez} (OMrez) as a function of move time in the atmosphere.

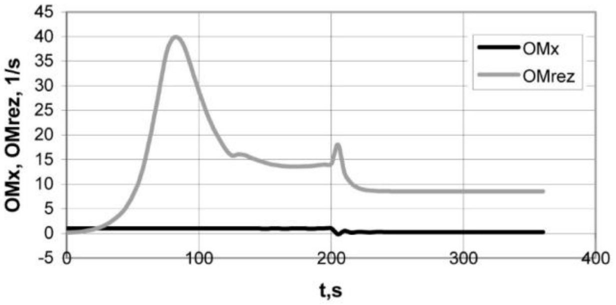

Figure 2. Graphs of angular velocity ω_x (OMx) rotation about the longitudinal axis of the landing vehicle and the resonance frequency ω_{rez} (OMrez)

The maximum value of the resonant frequency falls on the eightieth second movement of landing vehicle in the atmosphere.

In Fig. 3 presents graphs of velocity head and the lateral load in function of time of flight, which show that the maximum values of these variables accounted for the motion after the time of the landing vehicle intersection $\omega_x(t)$ and $\omega_{rez}(t)$.

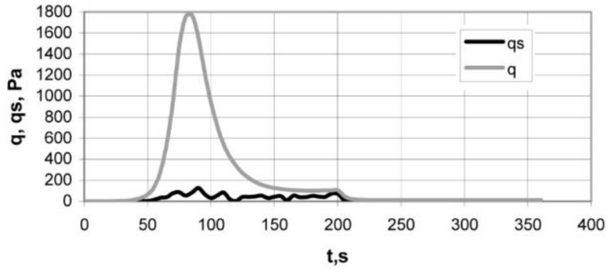

Figure 3. Graphs on dynamic pressure (q) and transverse loading (qs) in time for a nominal descent trajectory (ω_{x0}= 1.0 1/s)

At Fig. 3 shows that the highest values occur in the lateral load movement landing vehicle with large velocity head.

Let us consider in more detail the area of large lateral loads on the landing vehicle.

On Figure 4 a present of change in the transverse load (qs), which shows the following:

1. The maximum lateral loads are in the area of maximum dynamic pressure.
2. The maximum shear load is of the order of 120 Pa.

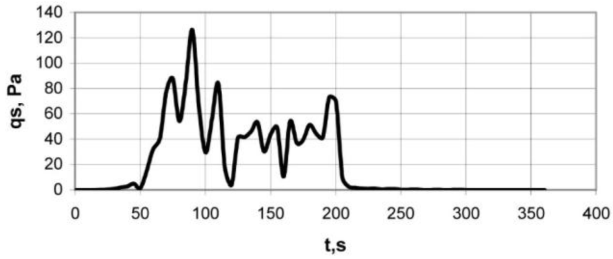

Figure 4. Graph of the lateral load (qs) in time for a nominal descent trajectory (ω_{x0}= 1.0 1/s)

On Fig. 5 shows a plot of the spatial angle of attack α_s, which shows that the angle of attack increases to the introduction AIBD.

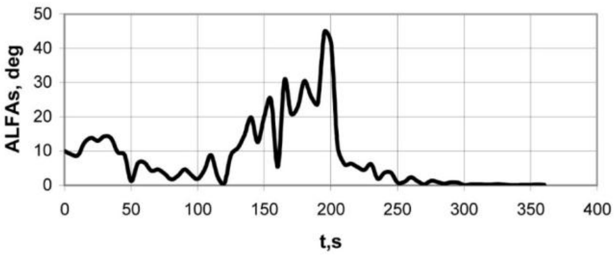

Figure 5. Graph of the spatial angle of attack α_s (ALFs) for a nominal descent trajectory

Thus the presence of landing vehicle small structural asymmetries (of inertia, the lateral displacement of the center of mass and aerodynamic asymmetry) produce large quantities of spatial angle of attack, even without the influence of the stiffness is not air brakes.

No stiffness braking device cause additional quantities of asymmetries that affect the dynamics of angular motion of landing vehicle.

The study did not influence the dynamics of rigidity braking device angular motion landing vehicle should be for the three stages of descent:

1. Stage movement the landing vehicle with PIBD after entering the planet's atmosphere.
2. Stage movement landing vehicle with PIBD after date of first entry angular velocity relative to the longitudinal axis of the landing vehicle and the resonant frequency to the introduction AIBD.
3. The final stage of the movement landing vehicle with AIBD until landing on the planet's surface.

C. Assessing the Impact of the Main Deformation Inflatable Braking Device on the Dynamics of Angular Motion of The Landing Vehicle in the Upper Atmosphere of the Planet

Consider the dynamics of angular motion landing vehicle with conical PIBD in the first stage of the descent trajectory in the atmosphere after re-entry until the intersection of the angular velocity of the longitudinal axis ($\omega_x(t)$) and the resonance frequency ($\omega_{rez}(t)$).

Preliminary calculations show that the flight path at this stage is about twenty seconds for the angular velocity of the landing vehicle (ω_{x0}=1 1/s) relative to the longitudinal axis of the re-entry. Analyze graphs of time-space angle of attack ($\alpha_s(t)$) and transverse loading ($q_s(t)$) for option entry landing vehicle from the angle of attack $\alpha_{s0}=10^0$ and the angular velocity of the longitudinal axis ω_{x0}=1 1/s.

On Figure 6 and Figure 7 the graphs of the angular velocity ω_x of landing vehicle rotation about the longitudinal axis and the resonant frequency ω_{rez}, as well as the spatial angles of attack, the lateral load and dynamic pressure at the beginning of the descent into the Martian atmosphere.

The moment of crossing the angular velocity of the longitudinal axis of the landing vehicle and the resonance frequency is 23 seconds.

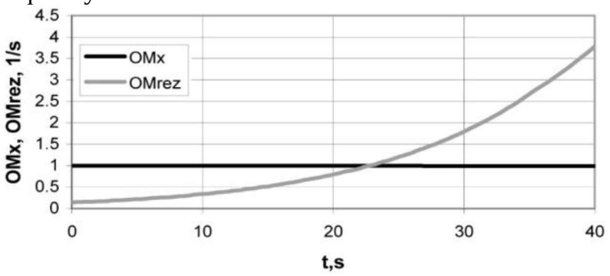

Figure 6. Graphs of angular velocity ω_x (OMx) rotation about the longitudinal axis of the landing vehicle and the resonance frequency ω_{rez} (OMrez)

At the time of intersection of the graphs and ω_x ω_{rez} the transverse load is qs=0.2Pa. Therefore strain PIBD virtually none.

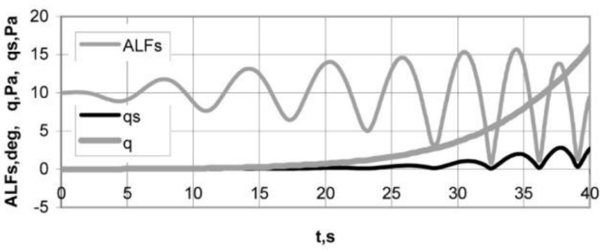

Figure 7. Graphs of dynamic pressure (q), the lateral load (qs) and the spatial angle of attack (ALFs) in the initial stage of descent

The presence of small structural asymmetries (of inertia, lateral displacement of the center of mass and aerodynamic asymmetry) landing vehicle with PIBD increases the spatial angle of attack when you are past the intersection and ω_x ω_{rez}. This is clearly seen on Figure 6 and Fig. 7.

On Fig. 8 presenting a picture of nutation-precession of the axis perpendicular to the plane of the landing vehicle in the velocity vector. Here, the solid angle of attack is the angle of nutation. Precession angle (ν) is the angle between the vertical plane passing through the velocity vector, and the plane of the solid angle of attack.

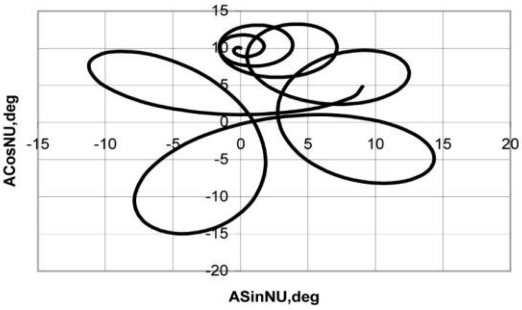

Figure 8. Nutation and precession of the axis motion in the plane perpendicular of the landing vehicle velocity vector during entry into the atmosphere

On Fig. 8 seen as progress through the intersection point ω_x and ω_{rez} begins not only change the value of the spatial angle of attack, but the nature of the vibrational motion of landing vehicle with PIBD.

Analysis of the graphs shows that the effect of deformation PIBD on the change in the spatial angle of attack slightly. This is due to the very small value of the transverse load at the beginning of the descent landing vehicle after entering the Martian atmosphere.

D. Estimation of Influence Deformation Inflatable Braking Device on the Dynamics of Angular Motion Landing Vehicle with PIBD in a Finite, Subsonic Phase

The results of calculations of the dynamics of angular motion of a solid body landing vehicle presented in Fig. 2 shows that at the time of disclosure and further descent landing vehicle with AIBD before it reaches the surface of Mars, the angular velocity of the vehicle with respect to the longitudinal axis of the much lower resonant frequency. Therefore, small structural asymmetry, as well as additional asymmetry of not rigidity AIBD should not greatly affect the dynamics of angular motion. In addition, landing vehicle with AIBD is statically stable unit.

A comparative analysis of the angular motion landing vehicle with AIBD with and without stiffness AIBD not. The results of calculations of the spatial angle of attack are shown in Fig. 9 and Fig. 10

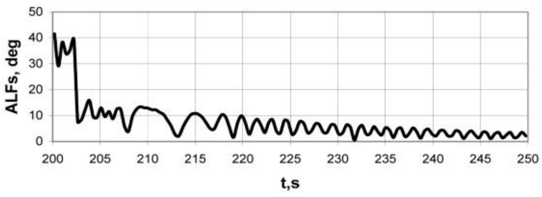

Figure 9. Graph of spatial angle of attack landing vehicle as a solid body

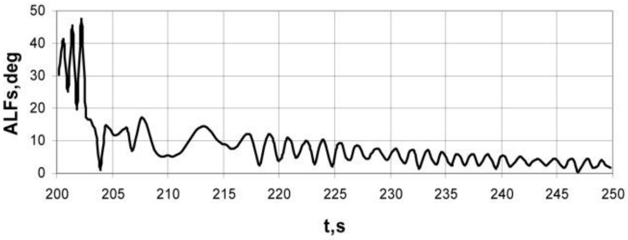

Figure 10. Graph of spatial angle of attack landing vehicle with not rigidity AIBD

Starting with 202 seconds of motion in the atmosphere of the landing vehicle starts AIBD rapid deployment, leading to a sharp decrease in the value of the spatial angle of attack. A comparison of the graphs presented in Fig. 10 and Fig. 9 shows that the presence of deformation AIBD on this trajectory leads to a small additional increase in the spatial angle of attack.

This effect does not change the stiffness AIBD spatial angle of attack for the following reasons:

1. The value of the velocity head is small, so small lateral load on the landing vehicle with AIBD.

2. Small transverse load causes a small deformation AIBD and therefore small quantities of additional asymmetries.

3. Landing vehicle with AIBD has sufficient static stability.

Fig. 11 paintings by precession-nutation motion of the longitudinal axis of the landing vehicle on the final trajectory for 10 seconds.

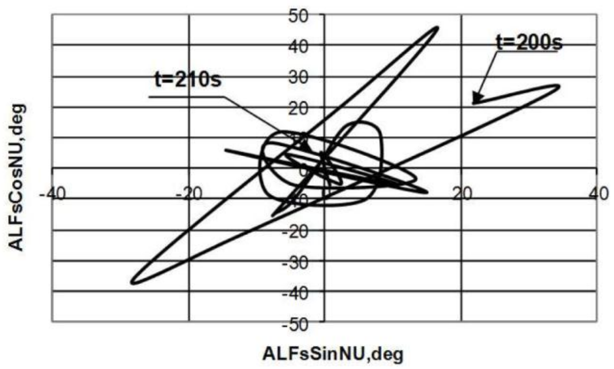

Figure 11. Graph of precession-nutation motion of the longitudinal axis of the landing vehicle on the final trajectory

It is seen that after the deployment AIBD (t = 202s) the value of the spatial angle of attack decreases rapidly. With about 217 seconds of flight landing vehicle moves with a slight decrease in the angle of attack.

III. Conclusion

1. Research indicates that this technology with the use of inflatable braking devices, originally developed for the descent into the conditions of the Martian atmosphere, can be used for terrestrial conditions. The preliminary results reveal a very good perspective, showing that the current design for the Mars landing vehicle can be used for the Earth.

2. Braking device deformation leads to the following disturbances:

- change the values of aerodynamic coefficients of axial force, the normal force in the plane of the solid angle of attack and the stabilizing of the moment;
- the appearance of additional small asymmetry in the form of a lateral displacement of the center of mass, moments of inertia, centrifugal and the asymmetry of the form.

3. The asymmetry of the external form of braking device in its deformation can lead to significant values of the coefficient of aerodynamic asymmetry. This in turn causes a change in the dynamics of angular motion of the landing vehicle. It is necessary to avoid the occurrence of such modes of motion of the landing vehicle.

4. The proposed method of investigation of the effect of deformation inflatable braking device on the dynamics of the angular motion of a space capsule enables the design phase to determine the required lateral stiffness of the braking device, which provides steady movement of various space landing vehicle on the entire trajectory of descent.

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International Scientific work:

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International Conferences:

International Astronautical Congress (IAC): in Beijing (China) in 2013, in Toronto (Canada) in 2014, in Jerusalem (Israel) in 2015, in Guadalajara (Mexico) in 2016;

40th Scientific Assembly of the International Committee for the Exploration (COSPAR 2014);

International Conference on Mechanical, System and Control Engineering (2016 Moscow, St. Petersburg 2017);

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