Analysis of emerging disturbing factors on the descent vehicle with inflatable mechanical devices during the descent stage

Vsevolod V. Koryanov 1, Sun Huanyu 1,2
1 Bauman Moscow State Technical University, 5, b1, 2-nd Baumanskaya Street, Moscow, Russian Federation, 105005
2 Harbin Institute of Technology, 92 West Dazhi Street, Nan Gang District, Harbin, People's Republic of China, 150001

vkoryanov@mail.ru

Abstract. The movement of asymmetric descent vehicles, in contrast to the movement of symmetrical landing vehicles, has a number of features. The main of them consist in the emergence of such dynamic phenomena as progressive self-rotation, vibrational-rotational resonances, nutation-precession instability, auto-oscillations, and others. In this paper, the entire landing trajectory is divided into main stages of movement, and then an analysis of some of the most unfavourable variants of movement at each stage is given. The conclusion is about the worst options. This must be taken into account when designing such descent vehicles with inflatable structures.

1. Introduction
At present, a large number of space missions are being designed. It is increasingly important to perform tasks to ensure that goods are returned to the small automated station from track or space. This may be the return of a sample in an interplanetary mission, or it may be the return of cargo from Earth orbit. For such missions, it is necessary to make a reliable landing for the landing vehicle. One of the most important stages in the movement of a spacecraft is the final stage - the landing of a spacecraft on the surface of the planet. The difficulty lies in the fact that it is necessary to reduce the speed from huge values during entry into the atmosphere to permissible values when landing on the surface of the planet. Another important limitation is the weight limit and the geometric parameters of the spacecraft.

Thus, the option to decelerate the space descent vehicle is to use inflatable braking devices. One of such projects in which inflatable braking devices are used is the MetNet project and its continuation RITD project [1-5]. (Figure 1). This is an aerospace recycling system that provides lift or resistance using aerodynamic shapes formed by aeration during reentry [6, 7].
Figure 1 shows the main stages of the movement: I - Atmosphere entry. Opening primary inflatable braking device; II - Entering the additional inflatable braking device; III - Braking with the additional inflatable braking device; IV - Landing vehicle touch the ground.

Compared with the traditional rigid pneumatic deceleration method, the pneumatic reducer has two functions in the reentry process: the heat protection function of the reentry section, the aerodynamic thermal load subjected to the hypersonic flow when entering the atmosphere, and the pneumatic deceleration function. The speed requirement is achieved by aerodynamic deceleration. Because of its light weight, flexibility, high strength and high temperature resistance, it can be folded into a small volume for easy loading. At the same time, it has a large resistance windward area after deployment, which can provide effective deceleration effect [8].

This paper is devoted to the four moments of the landing process. When the center of mass of the pneumatic deceleration device is displaced, the load of the inflatable device will change greatly, and it is necessary to analyze the influence of this change and the resulting imbalance of force on the inflatable device.

2. Theoretical part for the descent into the atmosphere
In this section, we will study the forces of landing vehicles in the atmosphere, allowing for small asymmetry [2]. In order to brake into the atmosphere, we will consider landing vehicles with pneumatic brakes, and two of them: the main brake for the upper atmosphere and the additional brake for the lower atmosphere. During the descent, the landing vehicle and its braking device are affected by important disturbances due to the external environment. Therefore, due to its flexibility, the inflatable device may be deformed and the movement may become unstable [9, 10]. Materials of other scientist who work in the field of flexible structures are presented here [11]. In addition, there are a number of articles on deployable structures in space that are also of interest to our research [12, 13].

We will use a method to analyze how the design parameters and aerodynamic coefficients affect the asymmetry from the longitudinal axis of the vehicle's velocity vector.

We can write:

\[ \omega_z = \frac{1}{2} \left[ J_{xy} \cdot (\omega_y - \omega_x \cdot \omega_z) + J_{xz} \cdot (\omega_z + \omega_x \cdot \omega_y) + J_{yz} \cdot (\omega_z^2 - \omega_y^2) + \right. \]

\[ \left. + (J_y - J_z) \cdot \omega_y \cdot \omega_z + q \cdot S \cdot l \left( m_{z0} + m_{zS} \cdot \frac{\omega_z \cdot l}{V} + C_y \cdot \frac{\Delta z}{l} - C_z \cdot \frac{\Delta y}{l} \right) \right], \]

Full equations are given in [1, 2].

In the future, we will change the values of the shift of the center of mass in order to obtain the most optimal variant from the point of view of the arising force factors.

Thus, taking into account the asymmetry of the descent vehicle with a device using an inflatable material occurs through a shift in the center of mass \( \Delta CM \) in Figure 2.

The main idea is that there is a shift in the center of mass of the inflatable structure (Figure 2).
3. Modelling part and analysis
We use software “Ansys” to solve this problem. We will focus on three moments in the landing process: heights of 60 kilometers, 20 kilometers and close to the ground.
We considered several options for the landing process: First, we believe that the vertical axis of the landing vehicle can be 0 degrees, 10 degrees or 20 degrees (Figure 3). Then, for each moment, we simulated the inflatable device to be offset by 5 degrees on one side. Finally, we consider the following data:
Speed to the ground (vertical speed component): Height 60 km: 2000 m/s, Height 20 km: 700 m/s, Height 0 km: 35 m/s.
We use the method of control points (Figure 4). Select seven points and observe the force at each point.

For each moment, we get the pressure cloud and the pressure and load at each point.
Let us analyze the data obtained, which are graphically shown in Figures 5-7.

At the second stage of the movement, the calculation results of which are shown in Figure 5, we can conclude that the maximum pressure at point 1 in the absence of asymmetries and in the presence of asymmetries.

At the third stage of the movement, the calculation results of which are shown in Figure 6, we can conclude that the maximum pressure at point 4 in the absence of asymmetries and at point 3, taking into account the presence of asymmetries.

At the fourth stage of the movement, the calculation results of which are shown in Figure 7, we can conclude that the maximum pressure at point 3 in the absence of asymmetries and at point 4, taking into account the presence of asymmetries.

The most loaded stage of movement is stage number 3.
Thus, we can conclude that at various stages of movement the maximum values are reached at various control points of the structure, thus, we can conclude that the entire structure of the descent vehicle carries heavy loads.

The pressure and load on the inflatable structure increases due to the deformation of the inflatable structure.

From these values, we find that asymmetry greatly increases the loads acting on the descent vehicle, and disrupts the stress balance.

4. Conclusion

As a result of the research performed in this article, the simulation of the movement of the descent vehicle with an inflatable device has been performed. The shape asymmetry was modeled through the center of mass shift. This approach allowed us to simulate the arising asymmetries in the shape of the descent vehicle with an inflatable braking device. Different values of the center of mass deviation were considered. Received the most dangerous variants of deviation. The obtained pictures of the occurrence of forces and pressure for some of the most dangerous options of movement with an asymmetric flexible inflatable braking device.

Conclusions about the most dangerous options must be considered when designing such spacecraft in the future.

References

[1] V.V. Koryanov. Method of calculating the descent of the spacecraft in the atmosphere using technology adaptation landing in different environmental conditions, IAC-14-C2.3.4, 65th Astronautical Congress, Toronto, Canada, 2014, 29 September – 03 October.

[2] V.V. Koryanov, V.P. Kazakovtsev. Dynamics of angular motion of landing vehicle in Martian atmosphere with allowance for small asymmetries. International Journal of Mechanical Engineering and Robotics Research, Volume 7, Issue 4, 1 July 2018, Pages 385-391.

[3] Jyri Heilimo, Ari-Matti Harri, Sergey Aleksashkin, Vsevolod Koryanov, Ignacio Arruego, Walter Schmidt, Harri Haukka, Valery Finchenko, Maxim Martynov, Boris Ostresko, Andrey Ponomarenko, Viktor Kazakovtsev, Susanna Martin, and Tero Siili. RITD - Adapting Mars Entry, Descent and Landing System for Earth, Geophysical Research Abstracts Vol. 16, EGU2014-5506-1, 2014, EGU General Assembly 2014

[4] The Mars MetNet Mission. Concept Drawing. http://fmispace.fmi.fi/old-metnet/index.php?id=100, (accessed: 05.02.2019).

[5] Pichkhadze K.M., Finchenko V.S., Aleksashkin S.N., Ostreshko B.A. Transformable vehicles descending in the atmospheres of the planets, Herald Federal State Unitary Enterprise Scientific and Production Association named after Lavochkin, 2. 2015, 4-13.

[6] Michele Iacovazzo, Valerio Carandente, Raffaele Savino, Gennaro Zuppardi. Longitudinal stability analysis of a suborbital re-entry demonstrator for a deployable capsule. Acta Astronautica. Volume 106, January–February 2015, pp. 101–110.

[7] Xia Gang ,Qin Zizeng ,Zhang Xiajin. Development status of inflatable thermal shield technology. Missiles and Space Vehicles , 2002 ; (1) :19~24

[8] Li Shuang, Jiang Xiuqiang. Review and Prospect of Decelerator Technologies for Mars Entry. Hangkong Xuebao/Acta Aeronautica et Astronautica Sinica 36(2), 2015, 36(2): 422r440.

[9] Canuto E. et al. Planetary landing: Modelling and control of the propulsive descent //Proceedings of the 31st Chinese Control Conference. – IEEE, 2012. – C. 7309-7316.

[10] Cho D. H., Kim D., Leeghim H. Optimal lunar landing trajectory design for hybrid engine //Mathematical Problems in Engineering. – 2015. – T. 2015.

[11] V.V. Leonov. The design features of inflatable large-scale mirror concentrators for space high-temperature solar power plant. Proceedings of the international astronomical congress, IAC 67, Making Space Accessible and Affordable to All Countries. 2016.

[12] V.S. Zarubin, V.N. Zimin, G.N. Kuvyrkin. Temperature Distribution in the Spherical Shell of a
Gauge-Aligment Spacecraft. *Journal of Applied Mechanics and Technical Physics* (2017) 58, pp. 1083-1090. https://doi.org/10.1134/S0021894417060141.

[13] Nerovny, N.A., Zimin, V.N. Light radiation pressure upon a wrinkled membrane - Parametrization of an optically orthotropic model. *Journal of Physics: Conference Series* Volume 991, Issue 1, 13 April 2018, Article number 01206 25th International Conference on Topical Problems of Continuum Mechanics, TPCM 2017; Tsakhkadzor; Armenia; 2 October 2017.