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To cite this article: Mingliang Zhang and Puyun Gao 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **295** 042101

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Study on Line Sail in the Process of Double-guided Parachute Deployment

Mingliang Zhang* and Puyun Gao

College of Aerospace Science and Engineering, National University of Defense Technology, Changsha, Hunan, 410073, China

*Mingliang Zhang's e-mail: 380512870@qq.com

Abstract. Double-guided deceleration parachute is widely used in large-scale space return activities. Compared with single-guided parachute, it has higher security, but its structure is more complex. This paper aims to study on line sail and analyse the effects of different initial dynamic pressure, separation speeds and angles of attack on the phenomenon during double-guided parachute deployment. The results show that for the double-guided parachute, the bigger the dynamic pressure of the return cabin is, the smaller the separation speed is, the bigger the angle of attack is, the more serious the line sail phenomenon will be.

1. Introduction

At present, the deceleration parachute in manned recovery system is usually straightened by single guide parachute, but double guide deceleration parachute is also used, such as Shenzhou series spacecraft in China. The line sail phenomenon refers to the phenomenon that the parachute rope or umbrella coat deviates from the direction of straightening and bends partially during deployment. This phenomenon may have unimaginable consequences for the parachute system, such as changing the deployment time, increasing the deployment force excessively, damage to the parachute clothes, and so on. Similar problems have been found in the high altitude airdrop test of the parachute recovery system of the US Mars Rover^[1] and the previous airdrop tests of the Shenzhou spacecraft^[2].

The process of parachute deployment and the line sail phenomenon have been studied. In the United States, Wolf^[3], Moog^[4] used the continuous deployment model and the simplified spring damping model to analyze the parachute deployment process. Purvis^[5-7] established a more complex linear model to predict the line sail phenomenon, but did not carry out in-depth analysis of its influencing factors. In China, Xumin Song, Wenke Cheng, Qingbin Zhang and Haitao Wang^[8-12] respectively studied the modeling methods of spring mass damping model and multi-rigid body model, and deeply analyzed the line sail phenomenon in the process of single-guided parachute deployment. Yuanyuan Lu^[13-14] and others studied on Line Sail during Mars probe parachute deployment, and analyzed the influence of initial speed, separation speed, angle of attack and other factors on the phenomenon. Mingliang Zhang and Puyun Gao^[15] analyzed the process of double-guided parachute deployment, studied its working principle, explained that line sail appeared in the process, but did not carry out in-depth analysis.

The structure of double-guided parachute is relatively complex, and the problem of line sail phenomenon cannot be avoided. In this paper, a double-guided parachute is used to simulate the deployment process under different initial conditions, and the effects of initial dynamic pressure, separation speeds and angles of attack on the line sail phenomenon are analyzed. The conclusion can



provide some references for the selection and design of the deceleration parachute structure in the process of recovery and landing.

2. Modeling of Double-Guided Parachute

In the dynamic modeling of the parachute deployment process, the theory of the return cabin, the canopy, the guide parachute package, the deceleration parachute package, the guide parachute, the deceleration parachute and other parts can be referred to [11].

Compared with single-guided parachute, double-guided parachute contains large and small guide parachutes, which are connected by limited-force connection belt. as shown in Figure 1. Therefore, it is necessary to judge whether the connection belt is broken during the deployment process.

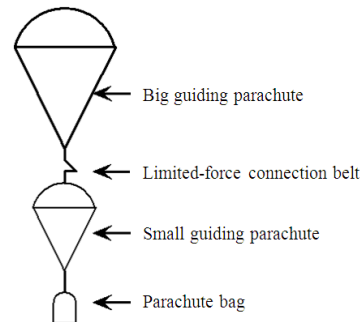


Fig 1 Double-guided structure

In other words, it is necessary to compare the maximum tension and the rated load of the limited-force connection belt.

$$\begin{cases} T_{c\max} \leq F_{cs} & \text{The belt is broken} \\ T_{c\max} > F_{cs} & \text{The belt is not broken} \end{cases} \quad (1)$$

Where $T_{c\max}$ is the maximum tension, F_{cs} is the rated load.

3. Numerical calculation results and analysis

The structural parameters, working principle and deployment process of the double-guided parachute system are detailed in reference [15]. When the dynamic pressure is small, the large guide parachute will not break off, and the deployment process is the same as that of the single-guided parachute. Therefore, this paper mainly analyses the deployment process of double-guided parachute under large dynamic pressure.

In order to better describe the line sail phenomenon, the maximum deviation distance in reference [14] is introduced here. As shown in Figure 2, the maximum deviation distance refers to the maximum vertical distance between the curve and the straight line connecting the starting point and the end point. The bigger the maximum deviation distance is, the more serious the line sail phenomenon is.



Fig 2 Maximum deviation distance

The initial deployment conditions of the deceleration parachute system are as follows: the initial altitude of the reentry module is 11km, the ballistic inclination angle is 56° , the angle of attack is -20° , the ejection separation velocity of the canopy cover is 22m/s, and the dynamic pressure of the reentry module is 10kPa, that is, the initial velocity is 235m/s.

Fig. 3 shows the curve of the maximum deviation distance with time under the above conditions. In the figure, the AB segment is the stage of ejecting the canopy and guiding the guided package from the return module, during which the maximum deviation distance is very small; in the BC segment, the maximum deviation distance increases with the pull-out of the large and small guide parachutes; in the CD segment, the large guide parachute is inflated and expanded, and the deceleration parachute system is straightened rapidly, and the deviation distance decreases obviously; and the DE segment is the process of pulling out the deceleration parachute after the breaking of the large guide parachute. In this stage, after the small guide parachute is deployed, the maximum deviation distance continues to decrease, and then fluctuates in a smaller range.

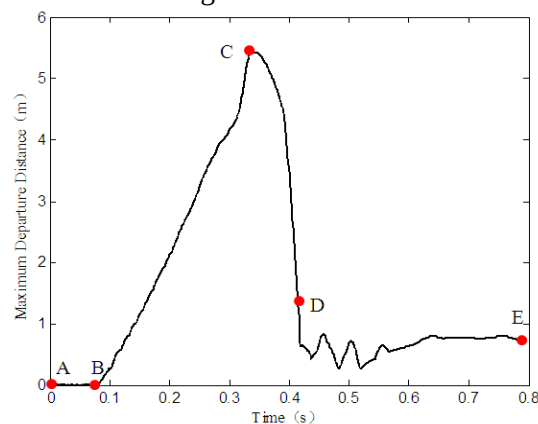


Fig 3 The curve of maximum deviation distance varying with time

In order to further study the line sail phenomenon in the deployment process of double-guided deceleration parachute, the process under dynamic pressure of 10kPa, 8kPa and 6kPa are analyzed. The calculation results show that the large-guided parachute breaks off under these three dynamic pressures. Fig. 4 shows the curve of maximum deviation distance under these three conditions. It can be found that the larger the dynamic pressure is, the larger the peak value of the maximum deviation distance is.

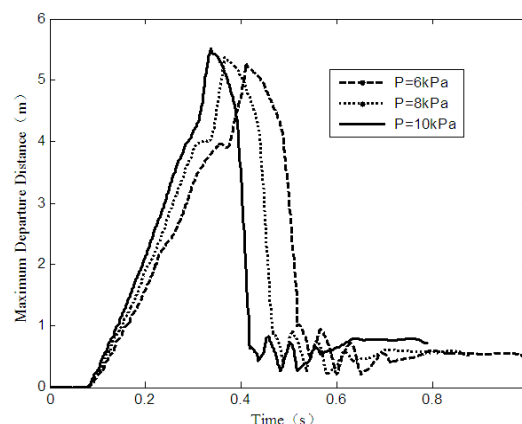


Fig 4 Maximum deviation distances under different dynamic pressure

The deployment processes at separation velocities of 15m/s, 22m/s and 28 m/s are analyzed. Fig. 6 shows the curve of the maximum deviation distance of the double-guided deceleration parachute under

these conditions. It can be seen that the larger the separation speed is, the smaller the peak value of maximum deviation distance is, but the difference is not significant.

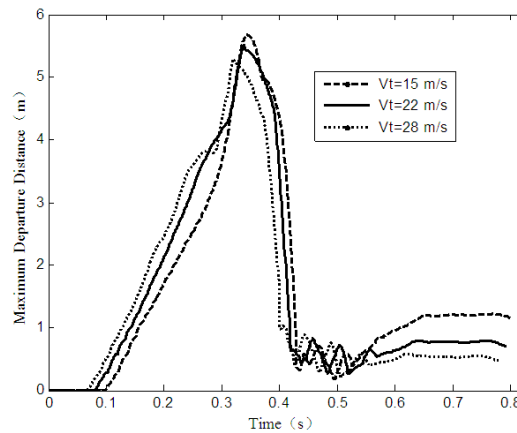


Fig 5 Maximum deviation distances at different separation velocities

The deployment process at angles of attack of 0° , 10° and 20° are analyzed. Figure 6 shows the curve of the maximum deviation distance under these three conditions. The Figure shows that the larger the angle of attack is, the larger the peak value of maximum deviation distance is.

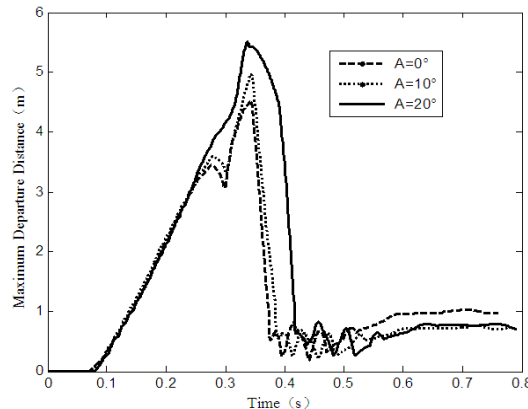


Fig 6 Maximum deviation distances at different angles of attack

4. Conclusion

In this paper, the phenomenon of line sail during the deployment process of a dual-guided parachute during recovery and landing of a certain type of spacecraft is studied. The effects of dynamic pressure, initial separation velocity and angle of attack on the phenomenon are compared and analyzed. The results show that for the double-guided deceleration parachute, the bigger the dynamic pressure of the return cabin is, the smaller the separation speed is, the bigger the angle of attack is, the more serious the line sail phenomenon will be. This conclusion has important reference value for the selection and design of the deceleration parachute structure in the process of recovery and landing.

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