Scientists develop a legged small celestial body landing mechanism for landing simulation and experimental test

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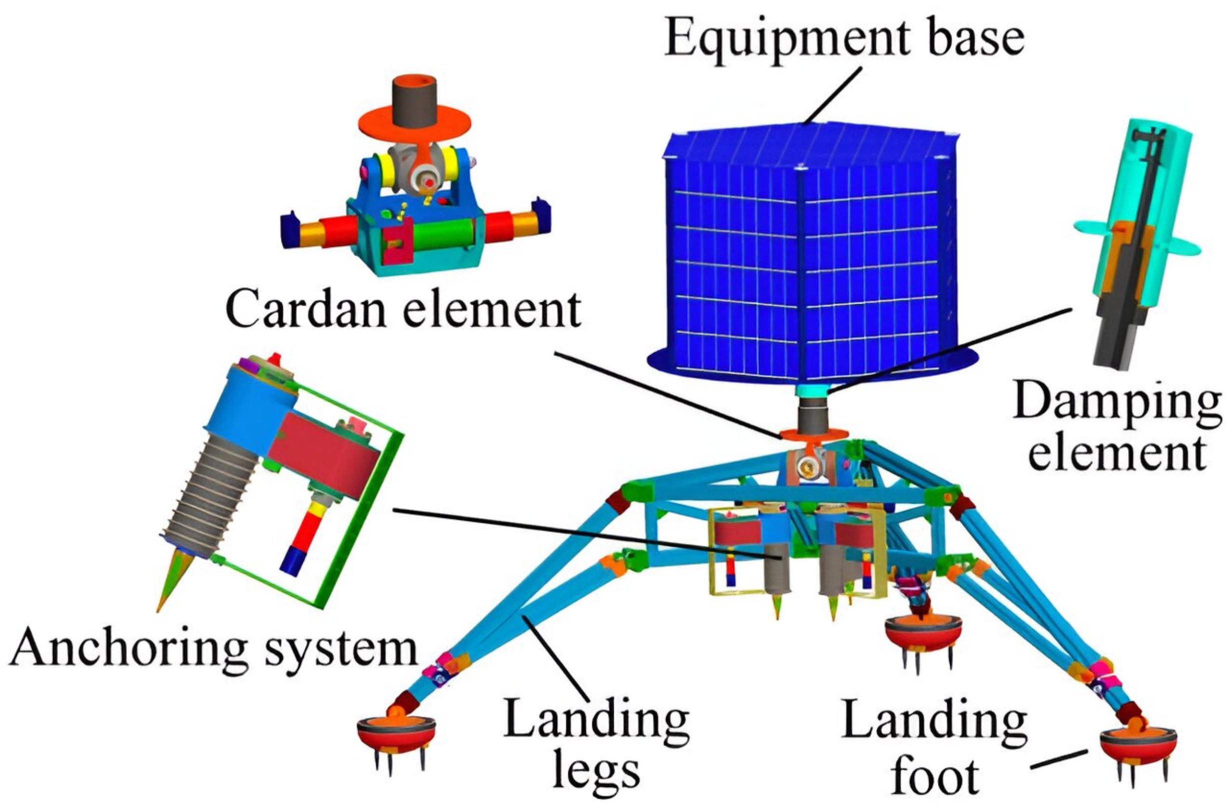


Schematic of the landing mechanism. Credit: *Space: Science & Technology* (2023). DOI: 10.34133/space.0066

Landing stably is a precondition for exploring a small celestial body in situ. The surface of a small celestial body frequently has weak gravity and is irregular, and the surface environment is unknown and uncertain. The landing mechanism tends to rebound and turn over, and the landing stability time is long. However, while most landing performance research has focused on lunar landing, there are differences between the surfaces of the moon and Mars.

Therefore, it important to study landing performance in different conditions in order to analyze the landing stability boundary, and to propose reasonable landing suggestions to support China's small celestial body exploration.

In a research article recently published in *Space: Science & Technology*, researchers from Beijing Institute of Spacecraft System Engineering, Harbin Institute of Technology, and Polytechnic University of Milan have established a simulation model of a landing mechanism under different landing conditions, analyzed the sensitivity of the key parameters affecting the landing performance, and verified correctness of the simulation via experimental tests, which can provide guidance for a landing mechanism to land stably on a small celestial body.

First, the authors briefly reproduce the landing mechanism and the landing simulation. The small celestial body landing mechanism used in the simulation contains a landing foot, landing legs, cardan element, damping element, equipment base, and more. In simulation, two scenarios are taken into consideration: the landing mechanism landing toward the landing slope with $V_x > 0$; and the landing mechanism landing away from the landing slope with V_x

In each scenario, three landing modes are classified according to the contact order between the landing foot and the landing slope, i.e. (a) 1-2 landing mode, (b) 2-1 landing mode, and (c) 1-1-1 landing mode (with 30° yaw angle). For all landing modes in both simulation scenarios, the landing mechanism turnover is prevented by the retro-rocket, and there is no sliding of the landing feet.

Items	Landing modes	Maximum acceleration	Stability time
Toward the landing slope	1-2 mode	7.3*g*	3.3 s
	2-1 mode	4.3*g*	1.5 s
	1-1-1 mode	7.5*g*	3.0 s
Away from the landing slope	1-2 mode	3.7*g*	3.0 s
	2-1 mode	2.3*g*	1.4 s
	1-1-1 mode	8.8*g*	2.5 s

Landing simulation results summary. Credit: *Space: Science & Technology*

The maximum overloading acceleration of the equipment base is less than 10 g, and the landing stability time is less than 4 seconds. This shows that the landing mechanism can land safely in different landing conditions. Additionally, when $V_x > 0$, the research shows that the 2-1 mode has the best landing performance among three modes, and 1-2 and 1-1-1 modes' landing performances are similar. When V_x

Secondly, key factors affecting the landing performance are analyzed.

Cardan element damping (c_2)

The landing stabilization time is significantly shortened and the overloading acceleration is weakened when c_2 is variable in comparison to constant c_2. The landing mechanism has better landing performance when c_2 is variable.

Foot anchors

The foot anchors affect the friction coefficient between landing feet and the landing surface. Slipping induces the landing mechanism far away from the landing point, which would affect the anchorage of the anchoring system. Friction between the landing mechanism and the landing surface should be high to avoid sliding of the landing mechanism. Overturning of landing mechanism due to high friction can be eliminated by retro-rocket thrust. Therefore, it is helpful to design foot anchors on the landing mechanism, as it can penetrate the landing surface and prevent or weaken sliding of the landing mechanism.

Retro-rocket thrust

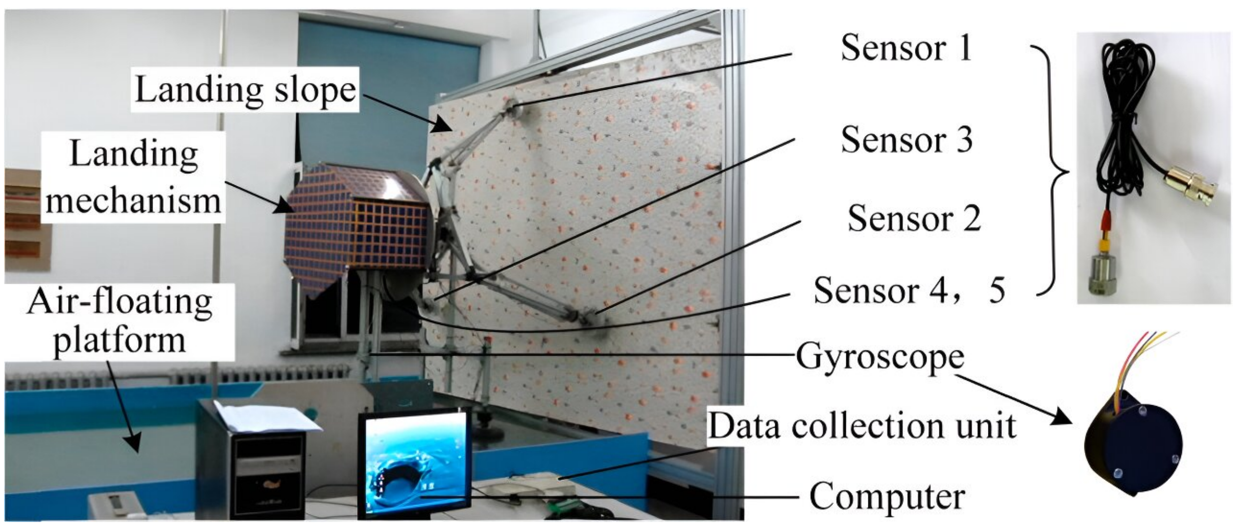
Retro-rocket thrust can prevent the landing mechanism from bouncing or turning; thus the retro-rocket thrust is helpful for landing successfully.

Landing slope

The larger the slope angle is, the higher the turning angular velocity of landing legs is, and the longer the landing stabilization time is. The influence of slope angle on equipment base overloading acceleration is not obvious. Therefore, the landing surface with smaller slope angle should be selected to reduce the landing stabilization time.

Landing attitude

When the landing mechanism lands in different landing attitudes within the allowable landing velocity, the maximum overloading acceleration is less than 10g and the landing stabilization time is less than 5 seconds. Landing performance is good. When the yaw angle is 60° (that is, the 2-1 landing mode), the landing mechanism experiences the minimum overloading acceleration and the shortest landing stability time, and the landing performance is the best.



Landing mechanism on the air-floating platform. Credit: *Space: Science & Technology*

Then, the validity of the simulation model is verified by tests. These tests are carried out on the air-floating platform. The landing accelerations are measured by acceleration sensors. Tests of landing on a 30° slope in the 1-2 mode, the 1-2 mode, and the 1-1-1 mode are conducted separately. These landing modes and velocities are imported into the simulation model. Landing performances between test and simulation are compared.

The overloading acceleration of the equipment base obtained by simulation is close to that obtained by test, and the simulation result is slightly larger than the test. This is due to the mechanical flexibility of the landing mechanism, which will produce flexible deformation in the test and absorb part of the impact load. The changes of landing leg turnover angular velocity and turnover angle in simulation and test are relatively consistent.

But between about 0.7 seconds and 2.5 seconds in the 1-2 mode, about 0.5 and 2 seconds in the 2-1 mode, and for the whole duration of the 1-1-1 mode, the landing leg turnover angle in test is less than that in simulation. The reason is that landing surface in test is hard wood and the foot anchors fail to penetrate the hard wood, which results in a slight slip of the landing mechanism. In addition, it is found that the 2-1 landing mode has the shortest stability time, and there is no obvious relationship between the overloading acceleration and the landing mode.

Finally, authors come to the conclusion that the following methods are helpful to improve landing performance:

- A three-leg landing mechanism should preferentially choose the 2-1 landing mode.
- Adjustable damping corresponding to landing conditions is helpful to improve landing stability.
- Foot anchors can reduce landing slip and shorten landing stabilization time. A retro-rocket on top of the landing mechanism can weaken or prevent rebounding when landing.
- The landing mechanism should preferentially land on flat areas.

More information: Zhijun Zhao et al, A Legged Small Celestial Body Landing Mechanism: Landing Simulation and Experimental Test, *Space: Science & Technology* (2023). DOI: 10.34133/space.0066

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