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“QingHuan” was launched: a lightweight inflatable device for end-of-life disposal

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The “QingHuan” drag augmentation device, developed by the Beijing Institute of Technology and Beijing Institute of Space Mechanics & Electricity, employs a foldable inflatable sphere to increase aerodynamic drag and accelerate orbital decay of low Earth orbit (LEO) spacecraft. Featuring compliant deployment, durable materials, and verified deorbit safety, the system requires no propellant and ensures reliable post-mission disposal. Ground and in-orbit tests confirm its effectiveness as a lightweight, low-cost solution for satellite end-of-life disposal and space debris mitigation.

As human space activities become increasingly frequent, the number of spacecrafts near low Earth orbit (LEO) has shown a significant growth trend. According to orbital dynamics principles, a large number of spacecrafts will remain in their original orbits for extended periods even after reaching the end of their operational lifetimes. This not only occupies limited orbital resources but also poses collision threats to the safety of nearby spacecraft. To maintain the safety of the space environment, countries have successively implemented policies and technical requirements for spacecraft end-of-life deorbiting. For instance, China has explicitly required low-orbit spacecraft to possess deorbiting capabilities since 2018. The European Space Agency (ESA) further proposed in 2023 that spacecraft should depart their orbits within five years after mission completion¹.

End-of-life deorbiting technology for satellites is one of the key solutions to the space debris problem. Traditional active deorbiting methods primarily rely on propellant combustion or electric propulsion systems, but for small satellites or low-cost missions, propellant consumption and system complexity impose significant limitations. In low Earth orbit, particularly at altitudes below 800 km, atmospheric drag is a critical factor affecting orbital decay. Drag-augmented reentry technology accelerates orbital decay by increasing the satellite’s frontal area during its end-of-life phase, enabling natural reentry. This represents a lightweight, low-cost, and widely applicable solution². Consequently, installing drag-enhancing devices on satellites to enable environment-assisted deorbiting has emerged as a cost-effective and viable approach³. The drag ball device, a representative example, significantly increases the satellite’s frontal area by inflating and deploying into a spherical shape, thereby accelerating orbital decay. Compared to drag sails, drag-sphere devices offer superior omnidirectional drag characteristics, require less stringent installation positioning, and maintain effective frontal area even during satellite oscillations or tumbling⁴. This ensures sustained

deorbiting efficiency. Consequently, drag ball devices are widely recognized as one of the primary means for end-of-life deorbiting of low-Earth orbit spacecraft.

However, drag ball devices still face multiple challenges in practical applications: the complexity of folding and unfolding large-sized spheres, the stability and protection of membrane materials in space environments, safety and risk assessment issues during deorbiting processes⁵, and the difficulty of achieving high-reliability designs while ensuring low cost and lightweight construction. Currently, all drag ball devices undergoing in-orbit verification internationally suffer from limitations of small size and short lifespan⁶, rendering them unsuitable for large satellites or high-orbit missions. These existing issues constitute the key technical directions for the subsequent design and verification of the “QingHuan” drag-enhancement deorbit device.

Overview of the “QingHuan” device

The “QingHuan” drag-enhancement deorbit device, jointly developed by Beijing Institute of Technology and Beijing Institute of Space Mechanics & Electricity, is deployed on the orbit retention platform of Beijing Galaxy Power Equipment Technology Co., Ltd. This device employs a foldable thin-film spherical structure that inflates into a 2.5-meter diameter sphere during the spacecraft’s end-of-life phase. This significantly increases the frontal area, accelerating orbital decay and enabling natural atmospheric reentry and burn-up.

During normal operations, the device remains folded during launch and early orbital phases to avoid interfering with primary spacecraft missions. Upon mission completion or predefined trigger conditions, its control system initiates inflation, rapidly deploying the membrane sphere into a stable spherical configuration. The deployed sphere increases the spacecraft’s frontal area, substantially enhancing atmospheric drag and accelerating orbital decay. Throughout the deorbiting process, the device requires no fuel consumption, features a lightweight structure for easy integration, and possesses protective capabilities to withstand variations in the space environment. The physical image of the “QingHuan” device is shown in Fig. 1, and its conceptual design and operational workflow are illustrated in Figs. 2, 3, respectively.

At ~19:39 on September 5, 2025, the “QingHuan” drag-enhancement deorbit device, carried aboard the Eros-1 02 satellite developed by Galaxy Power Aerospace Group, was successfully launched from the Jiuquan Satellite Launch Center (Fig. 4). It entered a 510-km sun-synchronous orbit. “QingHuan” will commence operations once the primary satellite’s other payloads complete their designated missions.

The “QingHuan” device is currently the world’s largest drag-enhancement deorbit device by sphere diameter, marking a significant breakthrough in China’s key technologies for space environment governance. Its successful launch not only provides a reliable technical solution for satellite end-of-life deorbiting but also accumulates experimental experience for the application of large-scale flexible structures in complex space

environments. This achievement offers robust support for future applications including rapid spacecraft deorbiting, space debris removal, and space security strategies.

Key technologies

Folding and unfolding. The thin-film drag-augmentation sphere is stowed for an extended period in a confined volume and inflated at end-of-life to execute the deorbiting task. Accordingly, achieving high-density, low-damage folding and compliant, smooth inflation-driven deployment is critical to successful operation.

First, folding criteria tailored to the volume-constrained spacecraft bay, together with low-damage criteria that prevent crease-induced compressive fracture, are formulated. Using the stowage-to-deployment ratio and crease area as core performance indices, an optimization model is constructed under engineering constraints to ensure a high deployment ratio while suppressing local damage and residual stress. Second, for the on-orbit inflation phase, the effects of gore count, inflation temperature, internal pressure, and orifice area on compliant deployment are analyzed to derive an optimal inflation strategy. This strategy maintains structural stability, prevents film tearing, and reduces the risk of oscillatory breakup of the

spacecraft at end-of-life, thereby enhancing the safety and stability of the deorbiting process.

On this basis, a symmetrically parallel Z-fold scheme is proposed⁷, achieving a stowage-to-deployment ratio superior to that of the flown BIT-1 mission. Two engineering prototypes of the drag-augmentation sphere have been fabricated, and compliant deployment has been successfully validated in ground vacuum-chamber tests. The present on-orbit experiment will provide in-situ confirmation that, under high-density stowage, thereby providing technical validation for smooth, controllable, and reliable folding-and-deployment performance for end-of-life drag-augmentation deorbiting missions.

Complex environmental protection. The low Earth orbit environment is complex, characterized by harsh conditions such as atomic oxygen erosion, radiation, and extreme temperature cycles. Additionally, the drag-augmentation sphere must operate in orbit for several months to years after inflation and deployment. Therefore, the materials of all components in the device must meet the requirements for vacuum environments to prevent mass loss and preserve material integrity. The sphere is constructed from composite polyimide fiber fabric, offering excellent shape retention and tear resistance. This is combined with a gas-tight layer and atomic oxygen-resistant coating, balancing shape stability, radiation protection, and resistance to atomic oxygen.

This experiment will validate the material’s ability to retain shape and resist radiation in complex space environments. The sphere’s surface employs a design with semi-reflective and semi-absorptive regions, facilitating long-term observation of attitude changes. This design also allows for comparative validation of the material’s protection against atomic oxygen erosion and its shape retention capabilities when subjected to micro-meteoroid impacts. The material and structural design ensure that the sphere provides sufficient safety margins during the on-orbit mission, effectively supporting the device’s long-term, efficient, and stable operation in space⁸.

Deorbit safety assessment. After the inflation and deployment of the drag-augmentation sphere, the entire system will remain in orbit for several months or even years. Due to the significantly larger cross-sectional area of the sphere compared to the spacecraft itself, the risk of

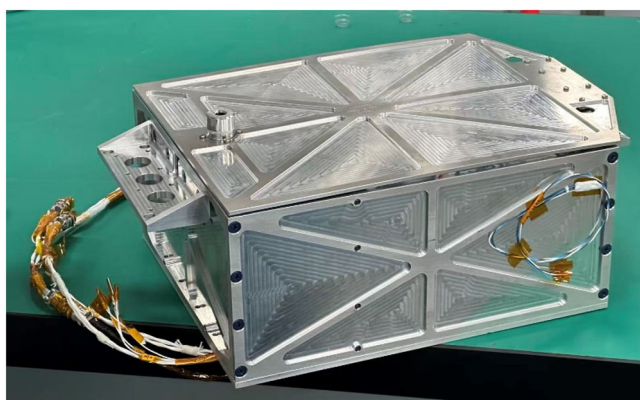


Fig. 1 | Physical image of the “QingHuan” device.

Fig. 2 | Concept of the “QingHuan” device.

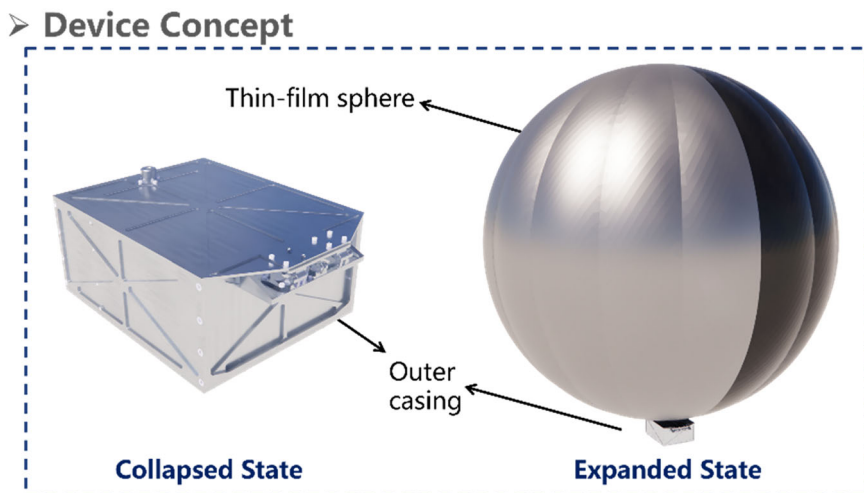
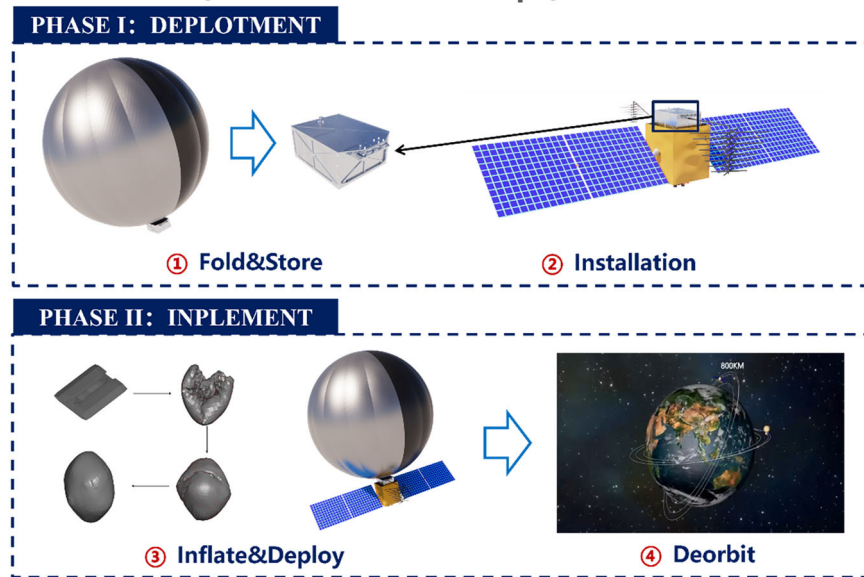


Fig. 3 | Workflow of the “QingHuan” device.

➤ Workflow (Two Phases, Four Steps)

Fig. 4 | “QingHuan” drag-enhancement deorbit device launch (*Eros-1 02 Mission, Jiuquan Satellite Launch Center, September 5, 2025*).

collision with space objects in the increasingly congested low Earth orbit will rise, and if the sphere is damaged and experiences air leakage, its deorbit efficiency will deteriorate. Therefore, before utilizing the drag-augmentation sphere for deorbiting missions, it is necessary to conduct a comprehensive safety assessment of the entire deorbiting process. This assessment will enable the pre-selection of the optimal deorbiting window for the sphere, ensuring the safety and reliability of the deorbiting procedure.

In the field of deorbiting process simulation and analysis, the research team has developed a safety evaluation technology tailored to the entire deorbiting process of the drag-augmentation sphere. This technology involves analyzing and predicting the space debris environment at the sphere’s time and spatial location, calculating the collision probability with debris, and generating intuitive risk distribution maps and key period alerts. Based on the evaluation results, the team has also proposed a global deorbiting window pre-selection technique, which optimizes periods and orbital conditions with lower risks during the mission cycle, providing a reliable safety guarantee for the deorbiting process.

In terms of software development, the team has independently developed China’s first deorbiting mission simulation and analysis software, which integrates the full process, from orbital propagation and debris environment assessment to deorbit mission window optimization. The team’s related technologies have earned first place in the China regional finals of the World University CubeSat Challenge and second place in the China Graduate Student Future Spacecraft Innovation Competition, showcasing the innovation and practical value of the research^{9–11}.

Future perspectives

With the continuous increase in the number of spacecrafts in low Earth orbit, autonomous end-of-life deorbiting and space debris removal will become critical tasks for ensuring the safety of the space environment. Based on the research achievements of the “QingHuan” drag-enhancement deorbit device, future related technologies hold broad application prospects in multiple areas. First, large-scale flexible drag-enhancement deorbit devices can be widely applied across different orbital altitudes and spacecraft types, providing efficient and controllable deorbiting methods for end-of-life spacecraft and significantly reducing the probability of debris formation. Second, this technology supports space safety strategies, including rapid-response orbital management, emergency incident handling, and orbital debris cleanup operations. In future space missions, integrating lightweight, low-cost deorbiting devices like drag balls is expected to enable full-lifecycle spacecraft management, enhance orbital resource utilization efficiency, and promote the sustainability of the space environment.

In the near future, the “QingHuan” device will undertake its next payload mission. Through payload tests conducted at varying orbital altitudes and under different satellite mass conditions, it will comprehensively evaluate the actual effectiveness of drag-sphere devices in achieving drag-assisted deorbiting for low-Earth orbit spacecraft, while comparing their adaptability to different deorbiting objectives. Furthermore, continued research on drag-assisted reentry technology will also drive the development of novel spacecraft designs. For instance, multifunctional flexible deployable structures can be integrated with other payloads to achieve synergistic

applications of drag-assisted reentry and mission payloads; The integration of intelligent control technologies and advanced composite materials will further enhance the stability and durability of the devices in complex space environments. Through these technological innovations, “QingHuan” system and its subsequent development plans will provide robust support for future applications such as rapid spacecraft deorbiting, space debris removal, and space security strategies, laying the foundation for building a clean, safe, and sustainably utilized space environment.

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Competing interests

The authors declare no competing interests.

Additional information

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