R E S E A R C H
INTRODUCTION

Realizing a debris-free outer space

Debris removal scenario

Currently, the number of debris objects that can be observed from Earth has exceeded 20,000. By including pieces 1 mm to 10 cm in size, which are difficult to observe from Earth, that number is believed to exceed 100 million. According to estimates by national space agencies including NASA, the debris in low Earth orbit, particularly in orbits of around 700 to 1,000 km and around 1,500 km, which are extremely congested with artificial satellites and debris, is expected to increase due to collisions with other debris, even if there would be no further space development. Against this backdrop, the need for debris removal, especially in recent years, is being seriously considered by many countries, and active discussions on the need for debris removal have begun, such as in the IADC.

Estimates of the specific extent to which debris must be removed differ by country; however, whether debris was removed by a total of 100 to 150 objects, based on simulations conducted by JAXA in collaboration with Kyushu University, or at a rate of 5 objects per year according to NASA, the result would be that the self-propagation of debris will be suppressed.

From minute objects like fragments to decommisioned satellites with an overall length of more than 20 m, there are various sizes of debris. Of all these, large debris such as spent rocket upper stages and satellites should be removed first. Rocket upper stages differ from satellites, which are equipped with solar panels and communications antennas, in that they have simple shapes. Research results published in recent years indicate that many will stop rotating as a consequence of Earth' s magnetic field and remain stationary keeping perpendicular to Earth, leading them to be considered easy to remove compared with satellites. Therefore, first removing rocket upper stages from the congested low Earth orbit is considered a realistic and efficient scenario, so we have continued the research and development of relevant component technologies.

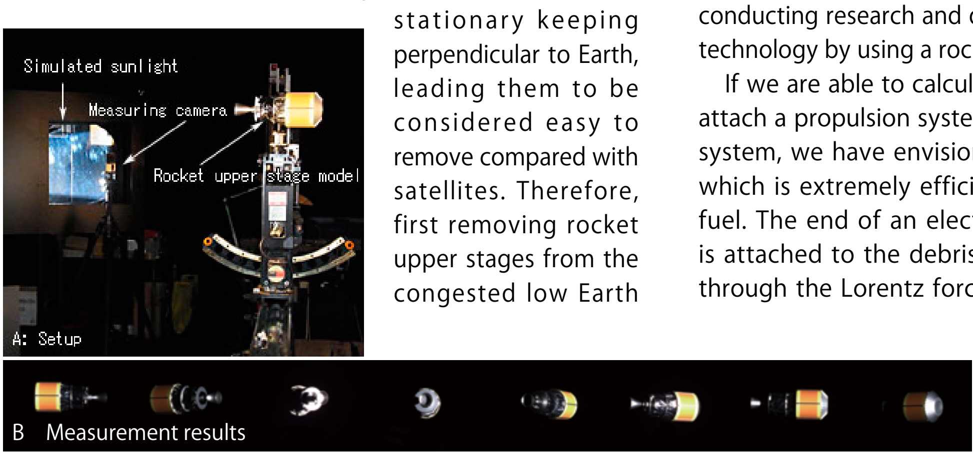


Fig. 1: Optical simulator

Removing debris quickly, safely and reliably

Debris removal is a pressing issue. If a large amount of debris (100 to 150 objects) is to be removed, technology that can realize this "quickly and efficiently" is required. For the removal of debris, technology is essential for "non-cooperative rendezvous" (to approach debris), "proximity operations" (performed after approach), then "de-orbiting" (to re-enter Earth' s atmosphere). During non-cooperative rendezvous, the direction and position of debris from a remote location must be measured in order to approach a location where proximity operations can be performed. These should be able to take advantage of existing Japanese technologies from the H-II transfer vehicle "Kounotori" and the asteroid explorer "Hayabusa" .

After approaching the debris in order to observe it, the next step is proximity operations. First, the distance relative to the debris as well as its motion must be estimated. In order to do that, "optical measurements" , in which the target is observed with an optical camera to provide its distance and attitude, are effective. This is a measurement method widely used, for example, in manufacturing facilities. However, in outer space, where there are no surrounding objects, such as atmosphere or a wall, to cause diffuse reflection of light and where intense direct sunlight is constantly changing direction, image-processing technology is necessary to be able to reliably respond to this harsh optical environment. Therefore, we have set up an "optical simulator" (fig. 1A), which can simulate the optical environment of outer space. Currently, we are conducting research and development of image-processing technology by using a rocket upper stage model (fig. 1B)..

If we are able to calculate the motion of debris, we can attach a propulsion system for removal. As the propulsion system, we have envisioned an "electrodynamic tether" , which is extremely efficient because it does not require fuel. The end of an electrically conductive cord (tether) is attached to the debris, transferring it to a lower orbit through the Lorentz force generated by the interference between Earth' s magnetic field and the current flowing through the tether, causing it to re-enter the atmosphere. (Fig. 2) Two methods are being considered for attaching the tether. One is a method of using a robot arm, for example, to hook the end of the tether into a 1-meter-diameter hole in a payload attachment fitting used as a base for mounting the satellite onto the rocket. (Fig. 3A) Another is a method where the side of the rocket stage, which is extremely thin for reduced weight, is approached and harpooned by the tether end to attach it. (Fig. 3B) This method is considered to be a safer operation since the tether can be attached from a distance of 10 to 20 m.

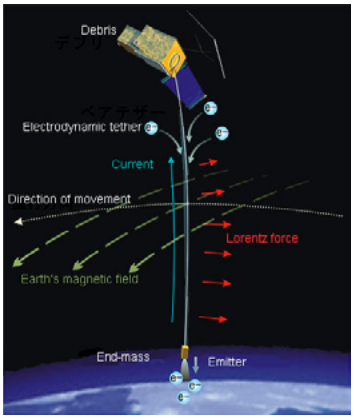
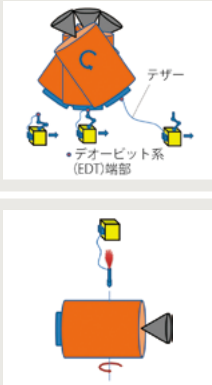


Fig. 2: Electrodynamic tether



A: Hooked adapter method
With an extension mechanism such as a robot arm, the tether end is inserted into the center of the adapter and hooked on to attach it. Various methods for hooking this are currently being studied.

B: Harpooning method
From a distance of 10 to 20 m, debris is harpooned by a solid rocket motor. From impact analyses, we consider that debris pieces will not fly off, even after being harpooned.

Fig. 3: How can a removal system (electrodynamic tether) be attached?

Arriving at the demonstration stage

Although there are differences in whether a hole is hooked or the object is penetrated, once the end of the tether is attached to the debris, it is then simply a matter of deploying the tether and causing the debris to re-enter the atmosphere (de-orbiting). This may sound easy, but our understanding of tether deployment, the flow of current and whether or not Lorentz forces are generated is limited without testing in outer space.

In 2013, seven small satellites will be launched by an H-IIA launch vehicle as piggyback payloads of an earth observation satellite. One of these satellites, Kagawa University' s small satellite "STARS-II" , is planned to conduct various demonstrations, including that for an electrodynamic tether that we have developed. We are looking forward to the success of Kagawa University' s demonstrations.

Concurrently, we are continuing to plan for a flight demonstration around 2015 of electrodynamic tether technology and technology for approaching a non-cooperative target. As one of the candidates for that, we are considering a demonstration test for deploying the tether from "Kounotori" after it has transferred its cargo to the ISS. Details for the actual demonstration scenario should be determined by the end of the publication year of this issue.

Until now, we have considered the scenario of removing debris in low Earth orbit. In fact, there is also a large amount of debris in high Earth orbit (geostationary orbit), which is at an altitude of about 36,000 km. However, debris cannot so easily enter the atmosphere from such a high orbit. Therefore, we believe that active satellites can be protected if debris was moved into an orbit of about 300 km higher than the geostationary orbit. An "ion beam" (fig. 4) is being investigated as a method of performing this. In the future, we intend to address specific component technologies that also concern the geostationary orbit.

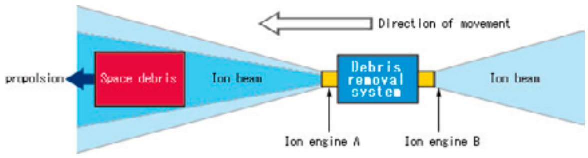


Fig.4: Changing debris orbit with an ion beam

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