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SPACE DEBRIS REMOVAL

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The research «Space Debris Environment Remediation», conducted by International Academy of Astronautics in 2011, contains review of various space debris removal technologies and methodologies, and analysis of their applicability to different debris objects and their types of orbits.

Our view of the problem of cleaning up the space environment is as follows.

Space debris removal problem is complex, i.e. it includes a range of tasks:

- ✓ ***Identification of space debris objects and their initial orbit parameters determination.***
- ✓ ***Prediction of space debris objects motion parameters.***
- ✓ ***Interception satellite optimal trajectory selection.***
- ✓ ***Ensuring the interception satellite's guidance and its rendezvous with a space debris object.***
- ✓ ***Ensuring an effective impact on an object that will guarantee its deorbiting.***

Challenges in solving indicated space debris removal tasks include the following:

- ✓ ***Because space debris objects do not have any tools for measuring their motion parameters, this task can be solved only by means (ground- or space-based) of location (radio- or optical).***
- ✓ ***Space debris objects vary in mass and size, i.e. the use of one device for effective removal of any objects seems to be impossible.***
- ✓ ***Space debris objects hold great amounts of energy (34…57 MJ/kg depending on orbit altitude), and for effective space debris removal it should be spent at least to 1% of this energy.***
- ✓ ***Usually, space debris objects spin chaotically, which makes it difficult to mount deorbiting devices on them.***
- ✓ ***Trajectories of most space debris objects lie in the region of functioning spacecraft, i.e. an impact must be applied to a specific space debris object and must not influence the functioning spacecraft.***
- ✓ ***Large space debris objects can be fragmented into smaller pieces from a strong mechanical impact, which in most cases leads to growth of space debris.***

Effective solution to indicated space debris removal tasks includes next:

- ***Use of space-based means of location for detecting and measuring the motion parameters of space debris objects. Today, for objects larger than 0.1 m it's done by ground-based means.***
- ***Forecast precision of space debris objects motion parameters should be 1…100 m (depending on an employed space debris removal technology) at least on the interval of one orbit pass (~100 minutes for LEO objects). Methods that are used today have forecast precision of functioning spacecraft coordinates ~1 km on the interval of twenty-four hours (i.e. ~70 m on the interval of one orbit pass).***
- ***Trajectory of an interception satellite, despite a type of used space debris removal technology, should ensure it can deorbit as many objects as possible, and does not influence the functioning spacecraft.***
- ***Guidance of an interception satellite and its rendezvous with a space debris object should be done by means of location and high maneuverability propulsion system.***
- ***Criteria of impact effectiveness on a space debris object can be drawn from its deorbiting duration.***

In our opinion, most effective impact on small, so as on large space debris objects (in terms of duration and cost of removal of one kilogram of debris), will be from smashing one with another object. By estimate, for fast (in just a few orbit passes) deorbiting of 1,000-kg space debris object from a 600…900-km altitude it's sufficient to smash it with an orbiting in opposite direction 10…15-kg object (a Kicker Load). The KL deorbits as well.

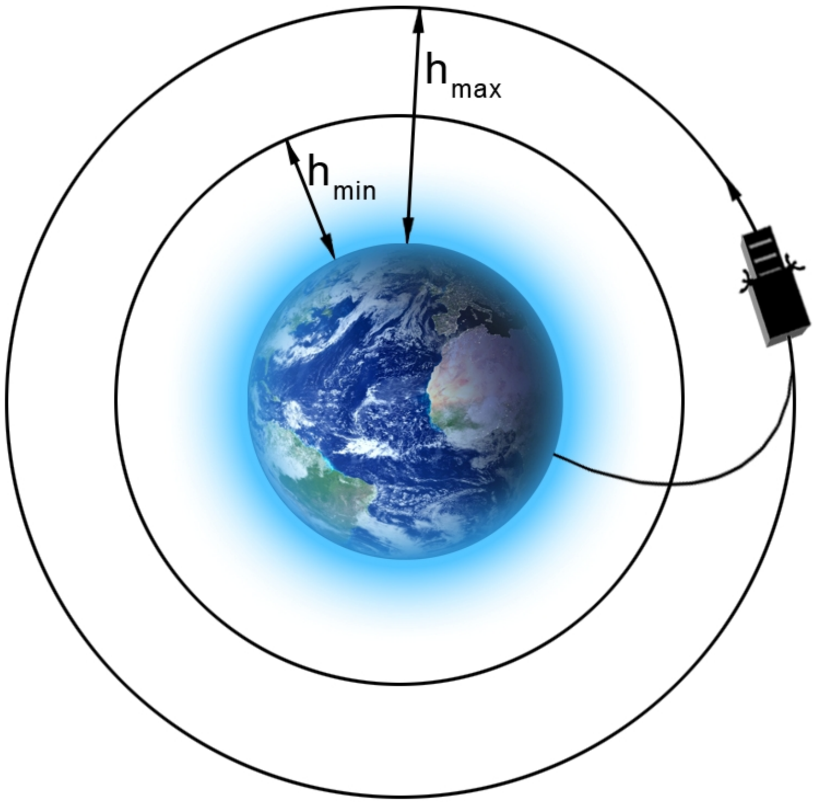
In realization of this technology, an acute problem that has to be found a solution to is to make sure a space debris object does not fragment from the impact of a kicker load, or in case it does, all the fragments will deorbit as well. Conducted in YSDO research shows this problem can be solved by using KL deformable structure of large size that will stall space debris object fragments after its collision.

The following space debris removal system for specific region, e.g. sun-synchronous orbits with constrained parameters, seems to be effective:

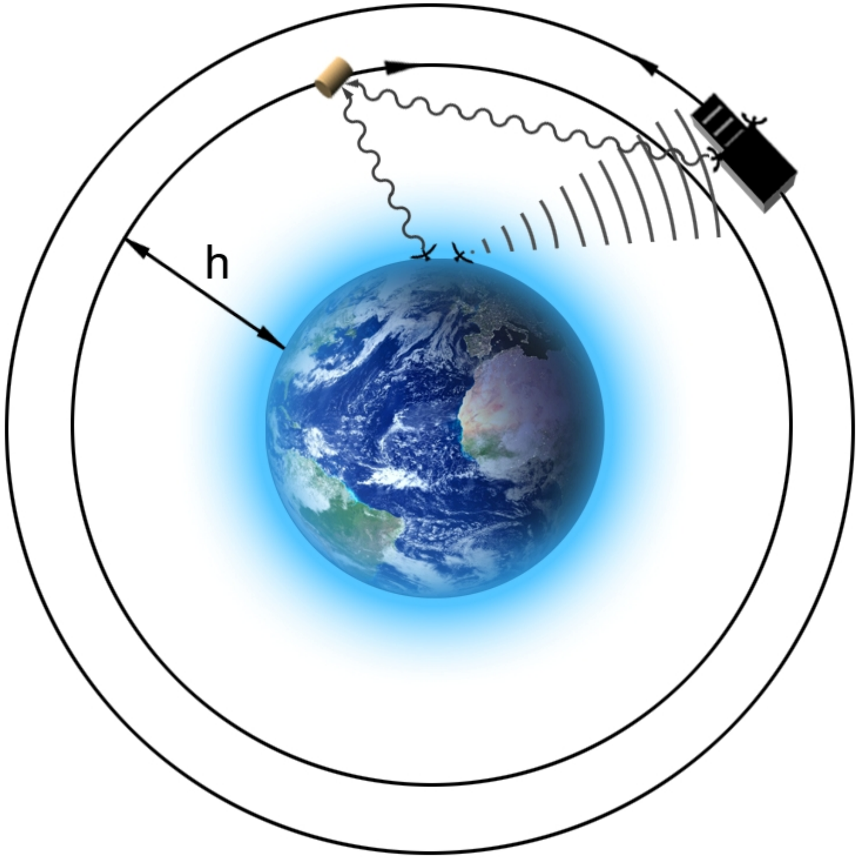
- altitude h_{min} to h_{max};

- inclination i_{min} to i_{max};

- local solar time in ascending node $t_{\Omega min}$ to $t_{\Omega max}$.

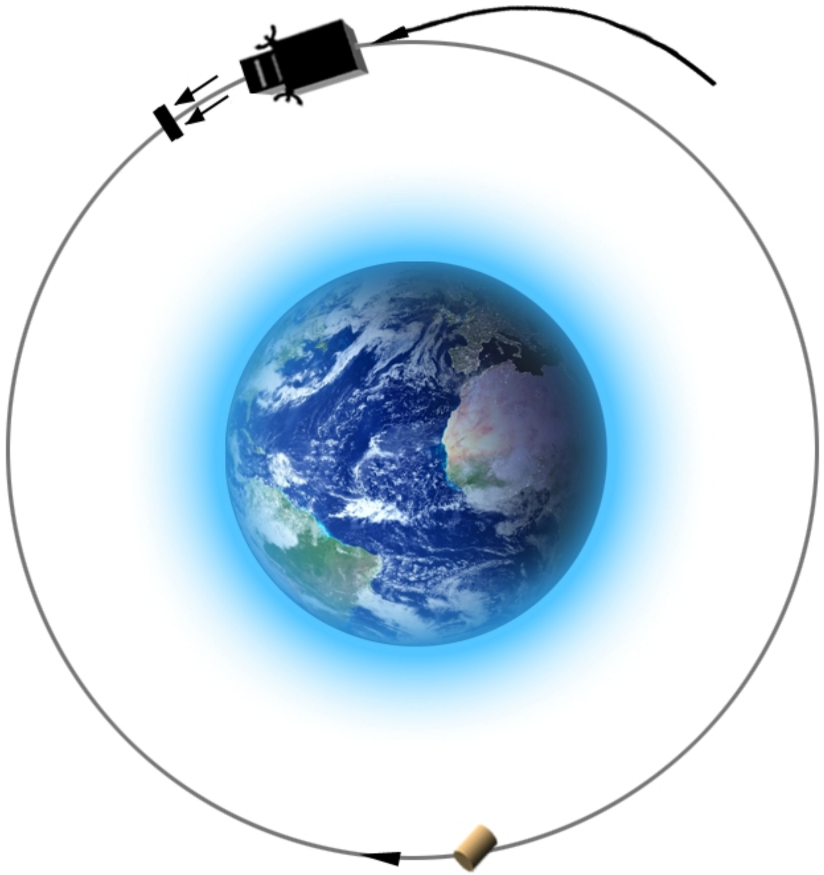


Before launching an interception satellite for cleaning up a specific range of orbits, a list of due to removal space debris objects has to be specified, and preliminary forecast of their trajectories carried out. An interception satellite with a set of kicker loads is launched into an orbit with a h_{max}-altitude, (180°-i_{max})-inclination and (12^h+$t_{\Omega max}$)-local solar time in ascending node.

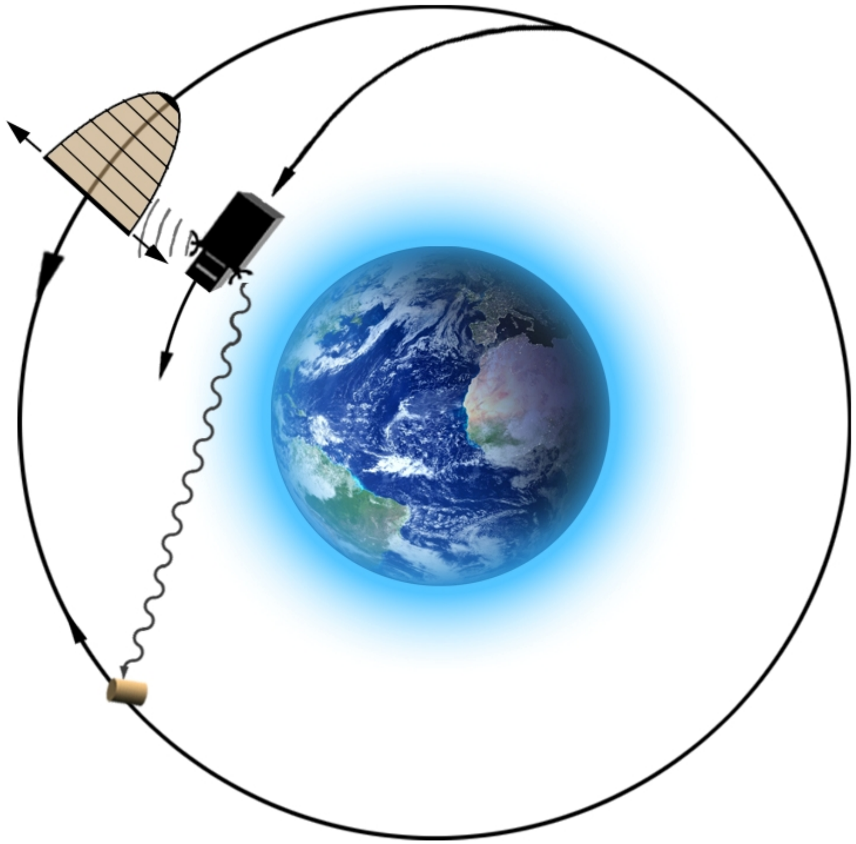


Due to long surveillance (with the help of ground-based means, and perhaps, interception satellite on-board means of location) forecast precision of an object's coordinates is brought to a few meters. It's sufficient to drive to this level of accuracy the forecast of just altitude and orbit binormal (trajectories tube radius) of a space debris object.

At the same time, ground control center (GCC) determines and predicts the interception satellite's motion parameters. On a basis of motion parameters forecast for a space debris object and the interceptor, GCC generates control commands and transmits them to the satellite.



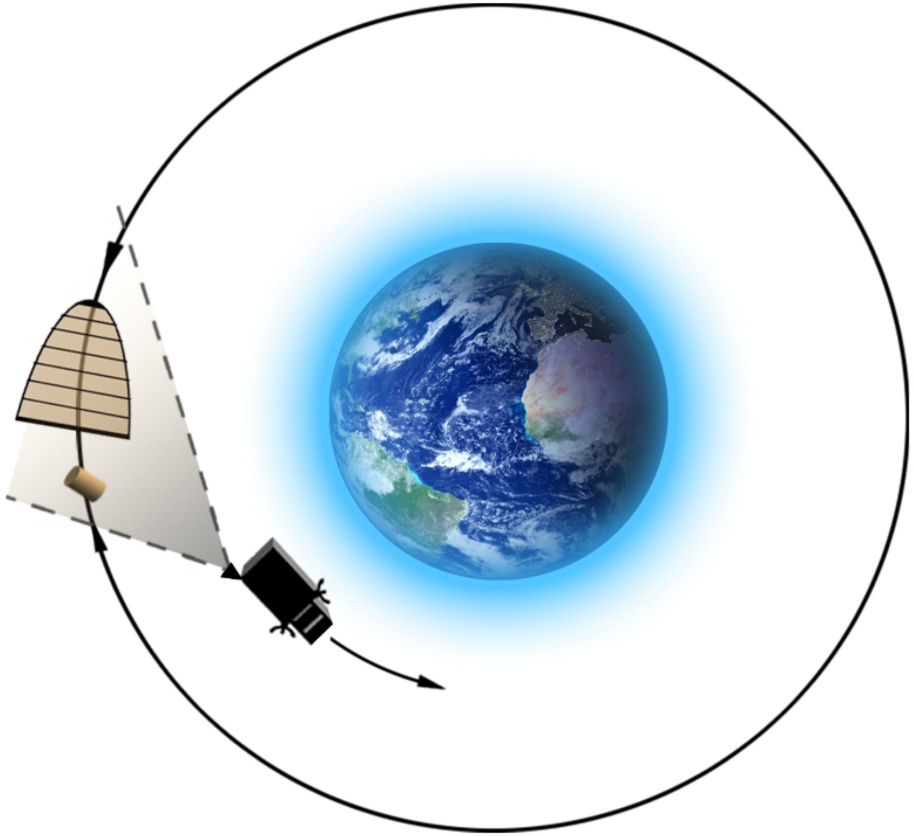
At a specified moment of time (less than an orbit pass) the interceptor using its high maneuverability propulsion system moves onto an object's trajectory but of opposite direction, and leaves there a kicker load.



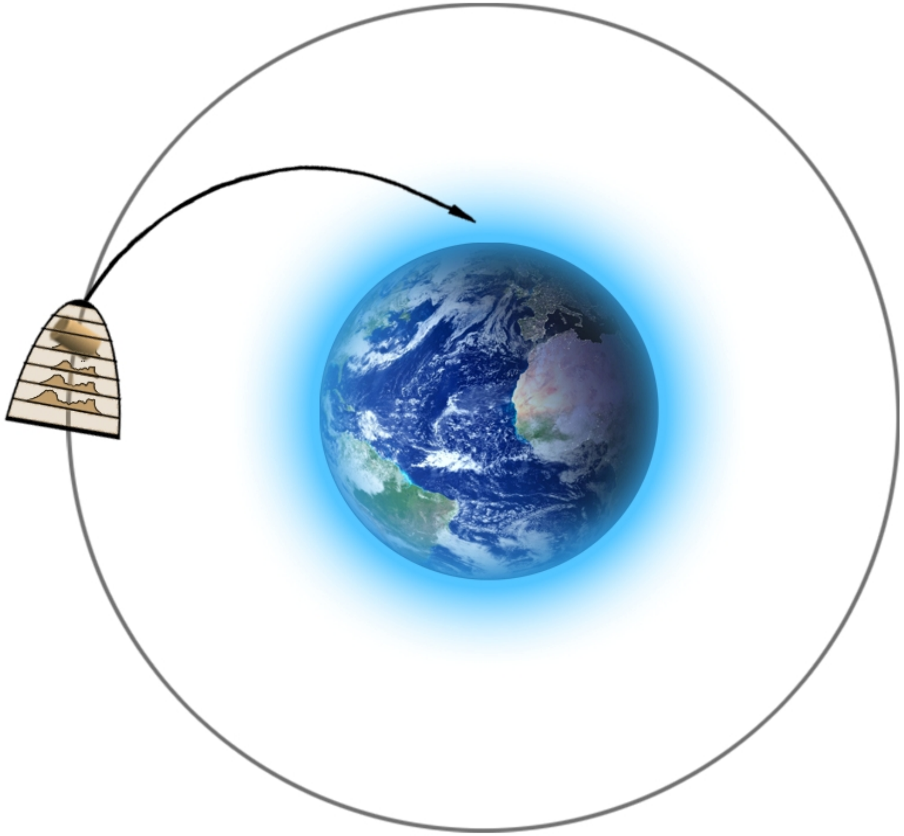
After a KL separates on a rendezvous trajectory, the interceptor moves to another, detects an approaching space debris object and takes it under surveillance.

A KL automatically unfolds to a necessary extent (10…20 m) and awaits a space debris object. If the need arises, trajectory corrections of a KL (up-down, left-right) can be performed with mounted on it micromotors via remote commands from the satellite.

PRINCIPLES OF KICKER LOADS SYSTEM OPERATION



When a space debris object collides against a sequence of deformable surfaces of a KL, a step decrease of an object's velocity and its fragmentation into separate pieces that stay inside the KL take place. The interceptor conducts surveillance over the process of a KL and space debris object colliding together with its camera for transmitting the reportage to GCC.



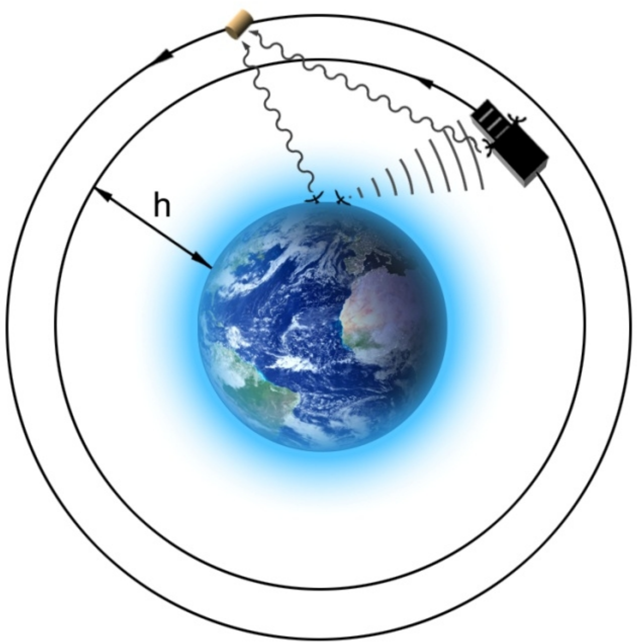
As a result of impulse loss, a space debris object (its fragments) along with a KL moves to an orbit that leads to deorbitation, and the satellite embarks on a process of deorbiting next object.

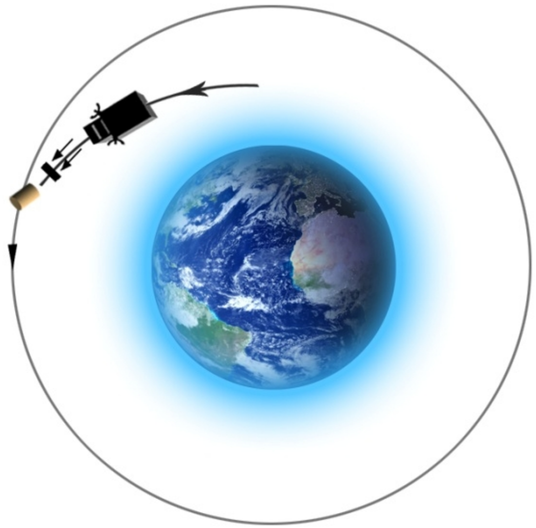
After cleaning up orbits of h_{max} the interception satellite transfers itself into lower orbits. In this fashion, the interceptor cleans up the specified range of orbits region by region until it gets to h_{min}. After mission is completed, it delivers itself to a graveyard orbit.

There's an option of space debris object removal of longer duration. In this case, the interception satellite leaves a KL not on a rendezvous trajectory, but on that of the space debris object.

1. On a basis of motion parameters forecast for a space debris object and the interceptor, GCC generates control commands and transmits them to the satellite.

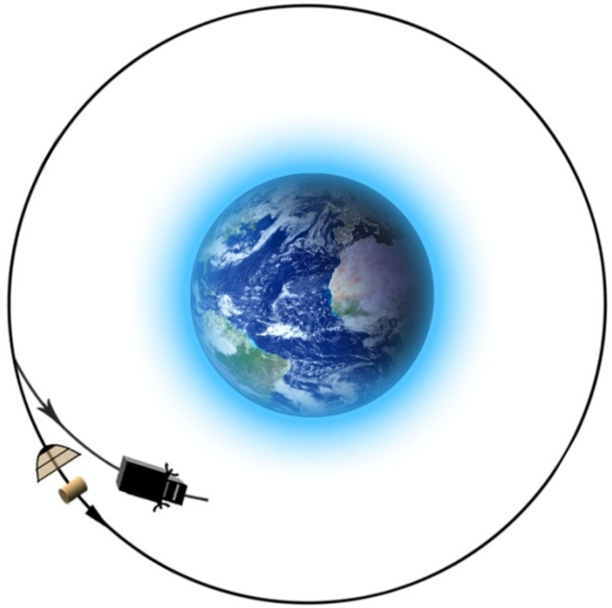
2. At a specified moment of time the interceptor using its high maneuverability propulsion system moves onto an object's trajectory and attaches to an object a deorbiting device.



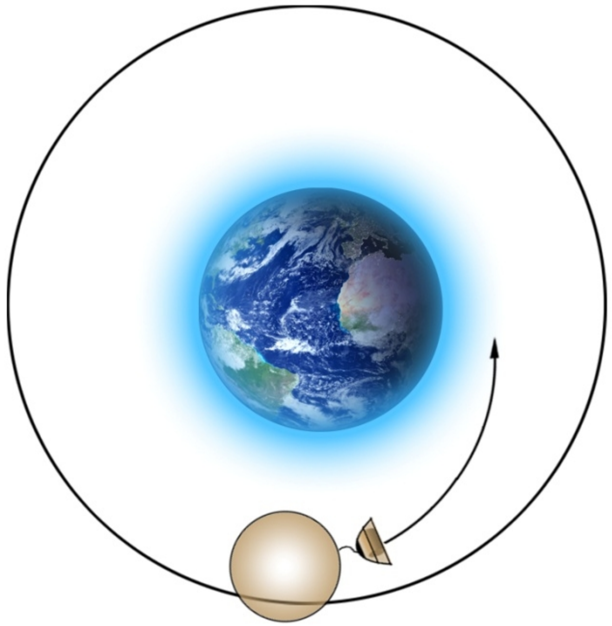


Guidance of a KL is carried out by remote commands from the satellite that conducts surveillance over the space debris object.

3. A deorbiting device is attached to a space debris object. The interceptor transfers itself onto the trajectory of another object.

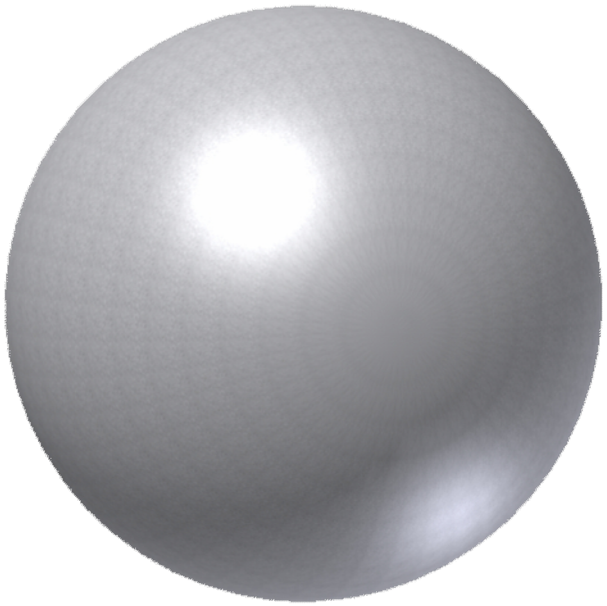


4. A deorbiting device (e.g. a drag augmentation inflatable structure) unfolds on an object.



The covers of balls and inflatable structures are made of light, thin, and strong material.

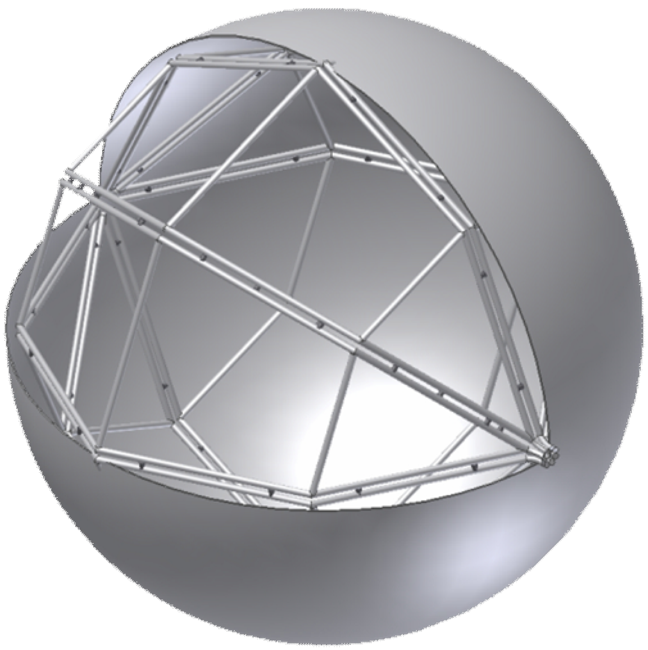
A whole ball-shaped shell



A group of several combined whole ball-shaped shells

Structure designs that increase survivability of an inflatable drag system when colliding with small (less than 10 cm) debris.

A frame ball-shaped structure



A segmental ball-shaped structure

Removal of LV upper liquid-propellant stages after delivery/separation of spacecraft can be carried out by mounted on propellant tanks reverse thrust nozzles with membranes. After propulsion system is shut down, membranes open and the pressurant from tanks begin to run through the nozzles, decelerating and twisting the stage around its longitudinal axis for ensuring the oriented travel.

To speed up the drag process of a stage the residual propellant in fuel tanks can be gradually afterburned.

Development proposals of:

- **a satellite system for effective space debris removal;**
- **an inflatable drag system that decreases a space debris object's orbit;**
- **a gas-dynamic removal system of LV upper liquid-propellant stages.**

Development process of a satellite system will include:

- ✓ ***Examination of principles of interception satellite operation and analysis of its various designs.***
- ✓ ***Computation of key parameters of an interceptor and KL.***
- ✓ ***Mathematical and physical simulation of the KL and space debris object collision process.***
- ✓ ***Elaboration of design and development documentation.***
- ✓ ***Manufacturing and testing of KL samples.***
- ✓ ***Manufacturing of an interception satellite demonstration unit.***

Project execution phases:

- ✓ ***Conceptual design.***
- ✓ ***Design and development documentation.***
- ✓ ***Experimental maturation.***
- ✓ ***Spacecraft demonstration unit manufacturing.***

Development process of an inflatable drag system will include:

- ✓ ***Selection of material and source of pressurant for the shell.***
- ✓ ***Computation of key parameters of an inflatable drag system.***
- ✓ ***Development of a pressurant control system.***
- ✓ ***Development of a storage system for inflatable devices inside the spacecraft and a system responsible for attaching them to space debris objects.***
- ✓ ***Elaboration of design and development documentation.***
- ✓ ***Manufacturing and testing of inflatable drag system samples.***
- ✓ ***Manufacturing of inflatable drag system demonstration units.***

Project execution phases:

- ✓ ***Conceptual design.***
- ✓ ***Draft design.***
- ✓ ***Engineering design.***
- ✓ ***Experimental maturation and clarification of development documentation.***
- ✓ ***Inflatable drag system demonstration units manufacturing.***

Development process of a gas-dynamic removal system will include :

- ***Conceptual scheme development of a depressurization system.***
- ***Computation of key parameters of a depressurization system.***
- ***Development of an afterburn system of residual propellant from either oxidizer or fuel tanks.***
- ***Elaboration of design and development documentation.***
- ***Manufacturing and testing of gas-dynamic removal system samples.***
- ***Manufacturing of gas-dynamic removal system demonstration units.***

Project execution phases :

- ***Conceptual design.***
- ***Draft design.***
- ***Engineering design.***
- ***Experimental maturation and clarification of development documentation.***
- ***Manufacturing of gas-dynamic removal system demonstration units on LV.***

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