# WALDO A System for Removal of Large Orbital Debris

By Rajiv Kohli and Ernest Y. Robinson

An effective orbital debris removal and relocation system is critically needed, given the large amount of debris, such as spent rocket bodies and dead satellites, in low Earth orbit (LEO). Presently, thousands of space debris objects are being tracked in order to allow planners to place new systems in an unobstructed orbit, or to help operators to maneuver space systems to avoid collision with space debris. Orbital debris poses disastrous interference and collision threats to neighboring satellites, leading to actual collision incidents. The recent 2009 collision of the active Iridium 33 satellite with the defunct Cosmos-2251 satellite was the first accidental hypervelocity collision between two intact artificial satellites in LEO. Several smaller collisions had occurred previously, often during rendezvous attempts, such as the Demonstration of Autonomous Rendezvous Technology (DART) satellite that collided with the Multiple Path Beyond-Line-of-Sight communications (MUBLCOM) satellite. Other threats can arise from uncontrolled reentry of decommissioned satellites such as the NASA Upper Atmosphere Research Satellite (UARS), the German Roentgen satellite (ROSAT), or other large debris objects such as the Russian Phobos-Grunt spacecraft all of which survived atmospheric reentry; similar future objects could cause harm to humans and property.

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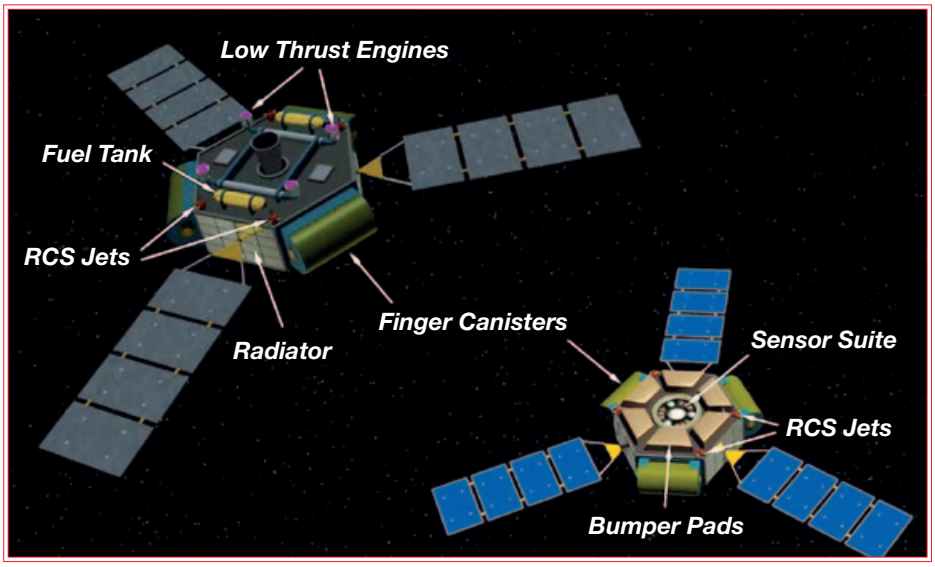
## A Hand in the Sky

At present, there are no proven means to relocate a satellite to a supersynchronous burial orbit, or to deorbit it to burn in the Earth's atmosphere. The Aerospace Corporation patented a satellite capture system

**Upper stages of expendable launchers pose great collision risk in Low Earth Orbit.** – Credits: U.S. Air Force

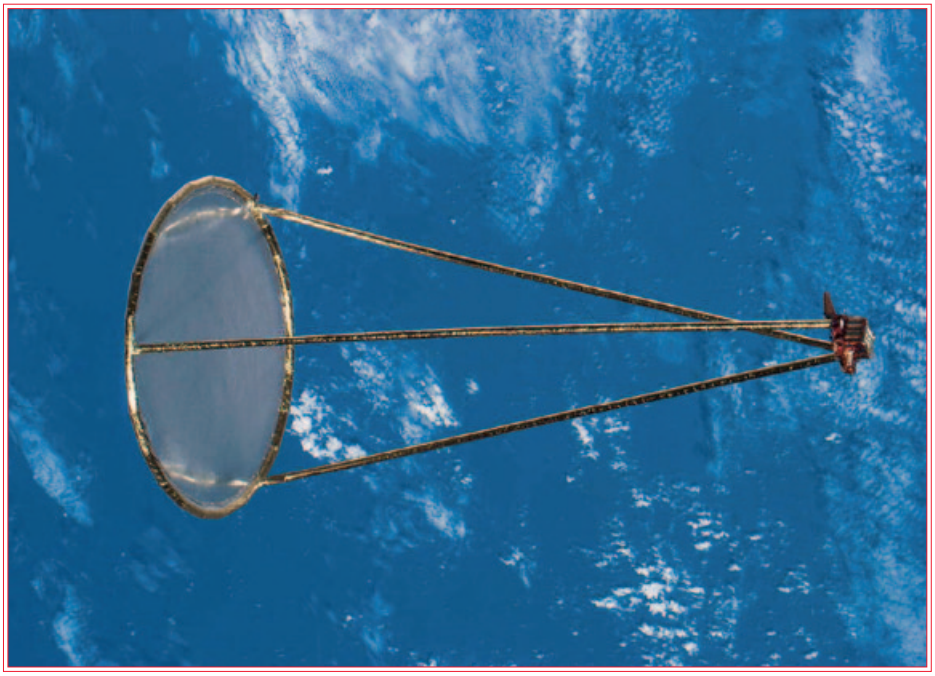
> "WALDO offers a possible relocation solution via a "hand in the sky""

called WALDO [1], which offers a possible solution via a "hand in the sky" device. WALDO was inspired by *"WALDO & Magic, Inc,"* a Robert Heinlein science fiction novel, in which the protagonist creates robotic hands, called Waldos, varying in size from microscopic to gigantic. The patented "satellite grabber" comprises a base satellite which, once in orbit, commands pneumatic deployment of long, slender, finger-like pods. The pods can be articulated by longitudinal tendon-like articulations, acting like a finger that curves around and captures the object. A combination of three such pods forms a "hand in the sky," a Waldo, that captures the target object for removal. In the present case, target objects are assumed to be passive and non-cooperative, as would be expected when collecting random dead satellites. The major advantage of WALDO is its ability to approach a target object from the front, embracing it all around with a controllable soft grab that would not damage appendages.




**Main components of WALDO.** – Credits: R. Kohli and E. Y Robinson

WALDO was inspired by the Jet Propulsion Laboratory (JPL) Inflatable Antenna Experiment (IAE) of May 1996. The IAE was released from the shuttle bay as a compactly stowed package and was deployed by inflation. The long sub-reflector pods and the main dish of IAE are inflated to create a very large space structure. These long slender pods, which extend far out in front of the sub-reflector to form a capture zone, are what inspired WALDO. In WALDO, the pods have articulation tendons running along the length of the spacecraft, enabling these sorts of large "fingers" to curve around and grab a space object.

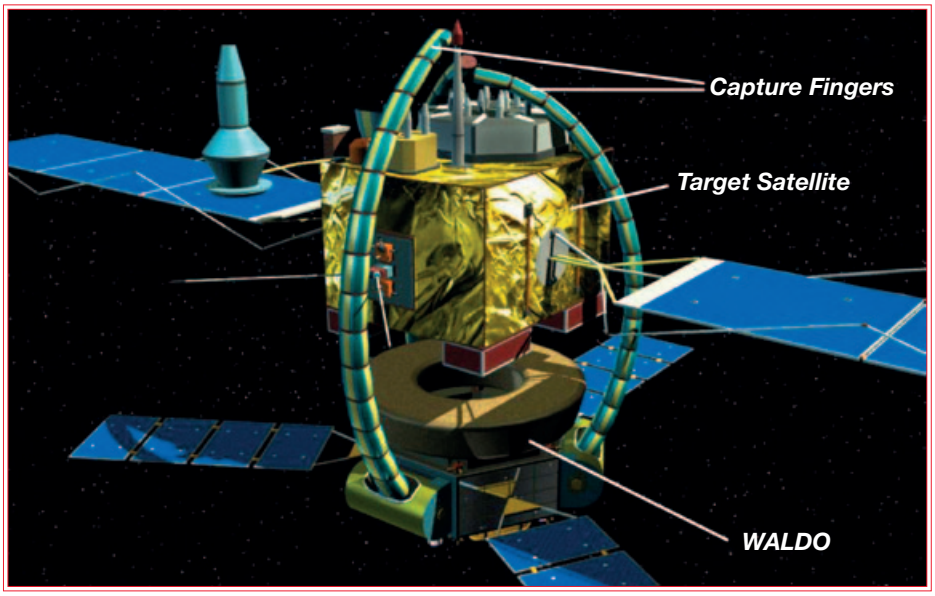


**The Inflatable Antenna Experiment of May 1996 in deployed configuration.**
Credits: NASA

## Concept of Operations

A detailed end-to-end mission concept of operations (CONOPS) for WALDO has been developed. A one metric ton space object, located at 400-600 km, would be captured and then either moved to a suitable burial orbit or deorbited. The CONOPS includes: analysis and assessment of the propulsion system; deployable mechanisms and deployable inflatable articulating fingers; long-range and close-in navigation and control; real-time image processing and target attitude; precise autonomous motion control to achieve formation flying; docking to target; removal to desired orbit or deorbit; control satellite/spacecraft sizing; design, fabrication and test plans; and flight demonstration test plans.

The CONOPS starts with a dead satellite, slowly rotating in a drifting orbit, which must be moved to a burial orbit. Ground tracking details of the target object are programmed into WALDO, along with detailed characteristics and images of the target satellite. WALDO plans the rendezvous trajectory using autonomous navigation, based on the NASA Advanced Video Guidance Sensor (AVGS) demonstrated in the Orbital Express Project [2]. WALDO, which is also capable of close-in navigation, ▸▸




**WALDO fingers deployed for soft embrace and capture of a target satellite.**
Credits: R. Kohli and E. Y Robinson

> "The soft grab target interface allows capturing any target geometry"

approaches the target using optical or imaging radar to establish orientation and motion of the object, and plans the final approach and capture. Navigating to a concentric rotation axis, WALDO establishes formation flying with the object, similar to the way in which the Space Shuttle and the Hubble telescope maneuver during repair missions.

As soon as WALDO nears the object at a distance suited to deployment of the fingers, around one to ten meters, the grasping fingers are pneumatically deployed. The fingers are sized and arranged to surround the selected debris object; as an example, the fingers can be thirty meters long, oriented at about 120° angles. The target is then captured as the fingers embrace it in padded physical contact. When the debris is within reach, the motor mechanism pulls and tightens the tendon lines causing the fingers to wrap around the debris to secure the grasp.

After capture, WALDO determines the removal trajectory to the disposal orbit, or the deorbit maneuver for the debris object, and fires its thrusters accordingly, performing either an insertion into the outer supersynchronous disposal orbit or a deorbit maneuver.

## Conclusions

The Aerospace Corporation patented satellite capture system WALDO is a "hand in the sky" concept that offers a possible solution for orbital debris removal and relocation. It comprises a base satellite that, once in orbit, commands deployment of articulating tendons to act like fingers that curve around and capture a target object. A combination of three such fingers captures a non-cooperating target object for removal. One major advantage of WALDO is its ability to approach a target object from the front and embrace it all around with a controllable non-damaging soft grab that will not damage or break off appendages. Plus, the non-specificity of the soft grab target interface would allow WALDO to capture almost any target geometry.

Watch the WALDO CONOPS:
*www.bit.li/waldo*

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[1] Robinson, E.Y. (2003). Spacecraft for Removal of Space Orbital Debris. U.S. Patent 6,655,637.

[2] Howard, R.T., et al. (2008). The Advanced Video Guidance Sensor: Orbital Express and the Next Generation. In Space Technology and Applications International Forum-STAIF 2008, AIP Conf. Proc. 969(1), pp717-724.

**Recovered propellant tank from a spent Delta 2 second stage that survived atmospheric entry.** – Credits: NASA