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ROGER - Robotic Geostationary Orbit Restorer

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Abstract

Since 1994, space debris has been an agenda item at the Science and Technical Committee of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). Meanwhile progress has been made with the implementation of “Space Debris Safety and Mitigation Standard Handbooks” However no binding agreement has been reached on international level, only recommendations for debris minimisation have been formulated: ”measures should be applied uniformly and consistently by the entire international space faring community; studies should be continued on future possible solutions to reduce the population of on-orbit debris”.

In support of the a.m. recommendations ESA has issued the ROGER (“**Ro**botic **Ge**ostationary Orbit **R**estorer") systems study which concentrate on the situation in the most valuable geostationary orbit, in particular on collision probability and on re-orbiting of satellites into disposal orbit.

This paper provides the technical and programmatic results of the a. m. ESA study. Specifically, the paper will:

- Describe the main tasks of the ROGER System, which consists of inspection services for satellite operators on request and the transportation of out-of-order satellites into a special graveyard orbit
- Describe the special means of the ROGER satellite to be capable to fulfill these task
- Describe the operational concept and its constraints
- Describes the justification of the selected scenario w.r.t. the arguments for the commercial applications

The concept foresees to approach a selected target satellite using rendezvous sensors and perform an inspection orbit. This inspection service by a zoom camera could be ordered by e.g. a satellite operator or a space assurance company. Another order could be the transportation of an end-of-life satellite into the graveyard orbit. Satellite operators are normally responsible to bring their satellites into graveyard by their own propulsion system and propellant mass. This residual propellant can be used to enhance the operational lifetime for the satellite and hence could make more profit. A part of this profit could be spent for the ROGER graveyard transportation service.

ROGER in its layout has specifically designed devices, to approach to the target, capture it, stabilize the attitude and transport it into a graveyard orbit. The necessary technical devices, the operational procedures and an overview about the commercial aspects will be given in this paper.

The presentation will be supported by a brief video film and models of the demonstrator and the proposed operational vehicle.

Introduction

The Phase A study contracted by ESA has been performed by the following partners:

- Astrium GmbH, Space Infrastructure, Germany
- Astrium Telecommunication & Navigation, Germany (GNC)
- EADS Launch Vehicle, France (Mission Analysis)
- Technical University Braunschweig, Germany (GEO Population, Simulator, Telescope)
- German Aerospace Center DLR, Germany (Robotics)
- MacDonald Dettweiler Space Robotics Ltd., Canada (Vision System)
- Space Applications Services S.A./N.V., Belgium (Ground System)
- Consultancy: Mr. Ed Ashford, SES/Astra Prof. K. Yoshida, Tohoku University, Japan

Since the altitude of the geostationary orbit is far beyond the outer residuals of the earth's atmosphere, every object launched into GEO or set free there will remain in the vicinity of the orbit forever. Only the above mentioned perturbations slightly modify the orbit of passive objects over the years. This led and still leads to an accumulation of objects within the GEO region over its nearly

40 years history of use. Currently, about 32 GEO spacecraft are launched per year while only 19 missions are officially terminated. In addition to the GEO traffic itself, the geostationary ring is regularly passed by further objects, e.g. upper stages orbiting on GTO. The growing GEO population as well as other objects passing through the geostationary ring pose a threat to the active payloads operating within this orbital regime. This hazard can particularly arise from collisions with spent objects or with fragments from other collisions or explosions. Although the current probability for an impact of a risk object larger than 1 cm, which could lead to severe damage or even complete destruction of the satellite, is still very low, explosion and collision activity will lead to a significant increase on the long term. This together with the mentioned N/S perturbation led to a significant population of objects outside the equatorial plane but with synchronous semi major axis. To preserve the global resource `geostationary ring' from a long-term contamination by spent spacecraft, several international corporations developed recommendations for the end-of-life disposal of GEO satellites. The International Telecommunication Union (ITU) suggests to re orbit to an altitude 300 km above GEO, the Inter Agency Space Debris Coordination Committee (IADC) developed a formula for a graveyard orbit between 245 km and 435 km above GEO, depending on the area-to-mass ratio of the spacecraft. But these recommendations still have no internationally binding character and are expected to be fulfilled by the satellite operators on a voluntary base only. An investigation of the orbital history of retiring GEO spacecraft performed by a NASA team revealed that even today, with the above mentioned recommendations being widely agreed within the space community, nearly one third of all GEO spacecraft, mainly of Russian and Chinese origin, are simply abandoned after retirement and not transferred to a graveyard orbit at all. Another third of the retiring satellites is dumped in an orbit at least partly above GEO, but below the recommended altitude regime. Hence, at the time being, only 1/3 of the satellite operators nominally re-orbit their spacecraft following the ITU/IADC rule. The remaining objects keep contributing to the GEO environment. The major problem that often makes a successful re-orbit impossible is the estimation of the fuel remaining (fuel gauging) for such a maneuver. Fuel gauging is usually based on information on the cumulative times a certain fuel valve was opened. This approach leads to an unknown inherent bias of the real amount of fuel remaining and the amount calculated. In order to make sure that a transfer maneuver can be performed even with these high uncertainties, even more extra fuel would have to be reserved for that maneuver. In the end this means that the time a GEO payload can be used to generate income for its operator would have to be reduced even more than the plain calculation of delta v required suggests. So the opportunity cost of a safe disposal to a graveyard orbit are even higher. With a robotic service satellite that is used to perform a re-orbit of payloads at the end of their lifetimes these payloads could be used a longer time resulting in increased income from extended service times for the operators. So, there is a quantifiable benefit of ROGER for satellite operators which have to fulfill certain disposal criteria.

Mission Scenario

The mission scenario begins with the launch of the ROGER servicing satellite with one of the large launchers, capable of transportation a 3.5 ton spacecraft into a geostationary orbit. When ROGER will have reached the GTO and is seperated from the launcher, it will perform by its own propulsion system the injection maneuver (apogee maneuver) to go into a nearby GEO, allowing for phasing to an orbit position, where the rendezvous maneuver to the first target satellite can start. This point (S1) will be about 230 km below and 500 km behind or in front of the target. A thrust maneuver (homing) allows the drifting to the point (S2) on the same orbit altitude as the target but 10 km behind. It will then follow a closing maneuver with 2 thrust impulses to reach the point S3 about 1 km away from the target. After a waiting phase the next closing maneuver will lead ROGER to point S4 about 100 m away from the target. After the observation and pose determination, ROGER will perform a maneuver to go into a half inspection ellipse and to reach the point about 100 m in front of the target. From here ROGER will approach to the target by a forced motion maneuver until about 15 m plus the S/C radius and will Again determine the pose and the rotation or tumbling rate of the target. Then ROGER will be pointed to the center of the target and the Capture mechanism, which could be the net capture mechanism or the tether-gripper mechanism, will be released. After the capturing the rotation or tumbling rate will be damped to nearly zero by the utility of the ROGER thruster on pulling the mechanism, which is connected by a tether with the capturing mechanism, against the rotation direction.

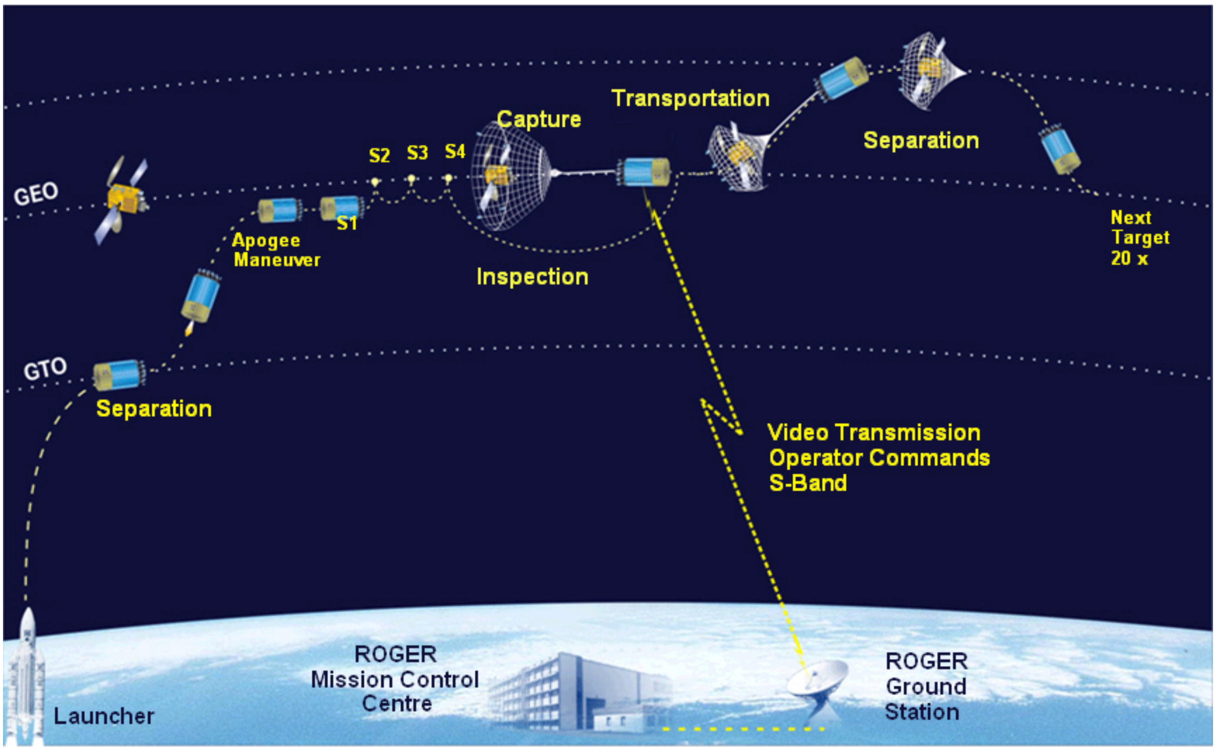

Fig. 1: Mission Scenario

After the stabilization maneuvers ROGER will inject the combined system by 2 maneuvers of a delta-v of 5.5 m/s or by several small maneuvers distributed over 24 hours into the graveyard orbit, where a separation will be performed.

Flight system description

The ROGER mission consists after the separation from the launcher of the following main elements, which are shown in fig. 2. The satellite platform with a total mass (BOL) of 3,500 kg and a propellant mass of about 2,700 kg is a derivative of a former very detailed designed Astrium platform, with detailed structural and thermal analysis. Most of the foreseen equipment is existing or of-the-shelf equipment, allowing to keep low the platform cost. The communication subsystem equipment is adapted to the special mission requirement, which requires a change of parameters in the link budget and also other components like antennas. Additionally are implemented two additional thruster clusters of 2 x 10 N thrusters each for the special transportation task to transport targets into the graveyard orbit connected by a tether with ROGER.

The avionic and propulsion equipment like high pressure tanks, valves and pressure regulators are located on the lower part of ROGER, whereas all equipment of the payload like the capture mechanism and the vision system are located around the upper platform. The solar generator consists of eight body mounted solar array plates between lower and upper platform.

The S/C with dimensions of 4 m length and a hectogonal shape with a diameter of 2.5 m, will accommodate several capture mechanisms, to have the transportation capability for several missions. There are proposed two different capture mechanism types:

- The net capture mechanism
- The tether-gripper mechanism

The first one is an expandable system, consisting of 4 flying weights, which will be accelerated into the direction of the target by a spring system, pulling out of a container a large net, which will tangle around the target. The net has a mesh width of 20 cm and will be closed behind the target by a rotor mechanism which is integrated in two of the four flying weights.

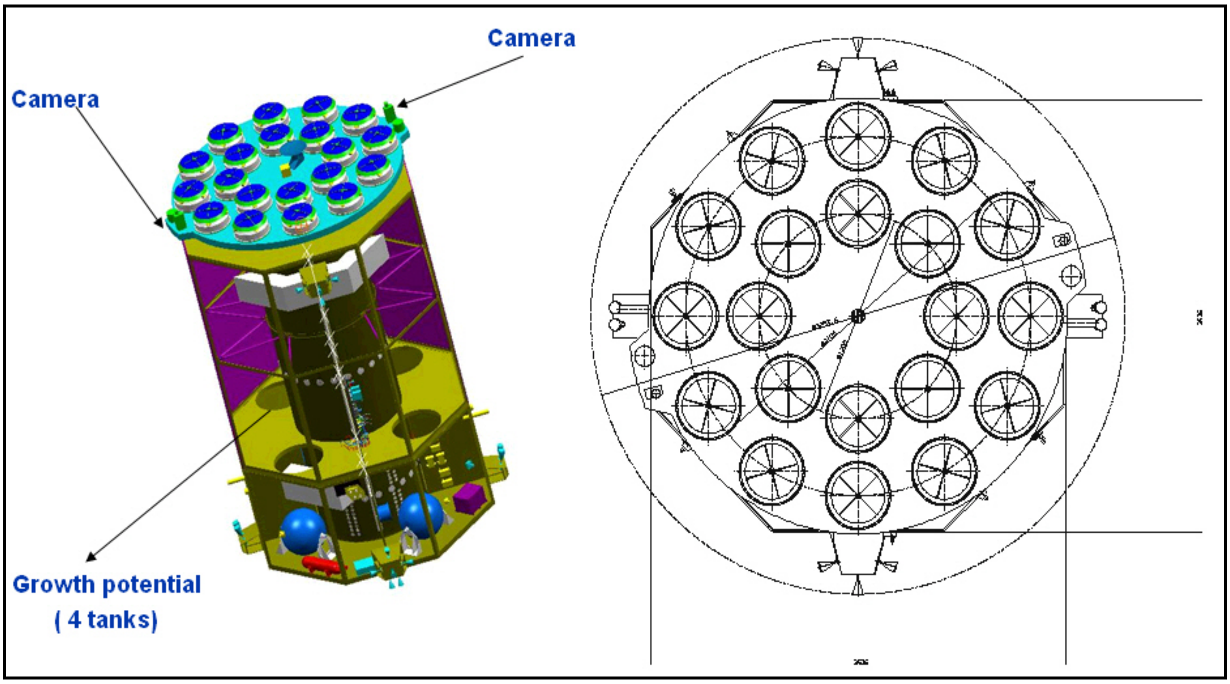

Fig. 2: ROGER Platform

The tether-gripper mechanism (TGM), with a total mass (BOL) of 40 kg and a length of 780 mm and a diameter of 480 mm is a free flying element but connected to ROGER by a tether, which includes a power- and data line, allowing to control the TGM via ROGER from ground. The motion to the target and rotations will be performed by a cold gas propulsion system using 12 thrusters of 1N thrust. On the upper platform are mounted 2 stereo cameras, a laser range finder and a 3-finger gripping element.

The net element could have different dimensions, depending of the target dimensions. This means that the mesh width will be 20 cm and the cord diameter would be 0.5 mm but the net area could vary between 10 m x 10 m to 20 m x 20 m or even larger.

Further mission elements are the Mission Control Centre, which comprises the operation control and the mission planning, then the Ground Network and a transportable Ground Station itself.

Net Capture Mechanism

The net capture mechanisms as depicted in action in the figure below has the task to capture the target, which could be a satellite or an upper stage or another debris part. The mechanism as shown in fig. 4 to fig. 7 has a total mass of about 9 kg and has the dimension of 400 mm in diameter and about 200 mm in height.

The net could have dimensions of 10 m x 10 m or 15 m x 15 m or if necessary larger, and is stowed in the net canister, which is in the mid of the four flying weights, which are accommodated with a special angle in relation to the LOS vector.

Each of the four flying weights have a mass of 1 kg and will be accelerated by a spring, which will be released by the separation of the cover, which itself will be deployed by a bolt cutter and a spring. The four flying weights will pull out the net, which is connected to the cover. The cover is connected by a 60 m long tether with a controllable reel (winch). The reel will be controlled by a motor, a tensiometer, the on-board computer and the ground operator in a closed loop, when the net has covered the target totally, a special mechanism, which is integrated in two of the four flying weights, see fig. 6, will close the net behind the target. The two mechanisms will roll up a cord, which connects all four flying weights. The mechanism consists of a rotor (spindle), which will be rotated by a motor and gets the power from a small battery. The system will be switched on by a micro-switch, which activates a timer. The timer starts the spindle rotation, which has achieved the goal of closing the net so far that the target cannot be lost after a few spindle rotations.

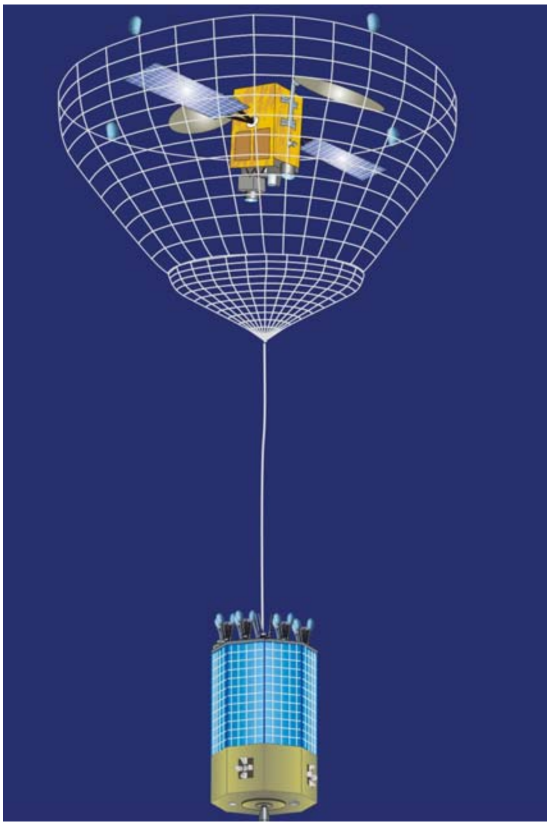

Fig. 3: ROGER with Net Capture Mission

Net Capture elements:

- Net Gun (net deployment mechanism using a spring system for acceleration - 1m/s - of 4 steel weights, which pull the net)
- Net with different dimension (10 m x 10 m or 15 m x 15 m or more) for different satellite sizes
- Tether of max. 60 m length and 1mm diameter for connection of net and ROGER
- Controllable Reel (winch) with a motor to control the tether length supported by a tensiometer and a cutter
- Vision System (camera) allowing the operator to control the capture procedure (LOS, range and pose determination)

Fig. 4: Net Capture Overview

Net Capture Parameter:

- 1Net dimension:10 m x 10 m (15 m x 15 m)
- Mesh width: 20 cm x 20 cm
- Material: Polyamid A; diameter: 0.5 mm
- Net mass: ~1.0 kg; volume: 0.8 dm³ (litre)
- Mechanism unit structure: 3.0 kg
- Mass of 4 steel weights: 4 x 1.0 kg
- Total mass of the net capture mechanism: 9.0 kg
- A spring system accelerates the weights

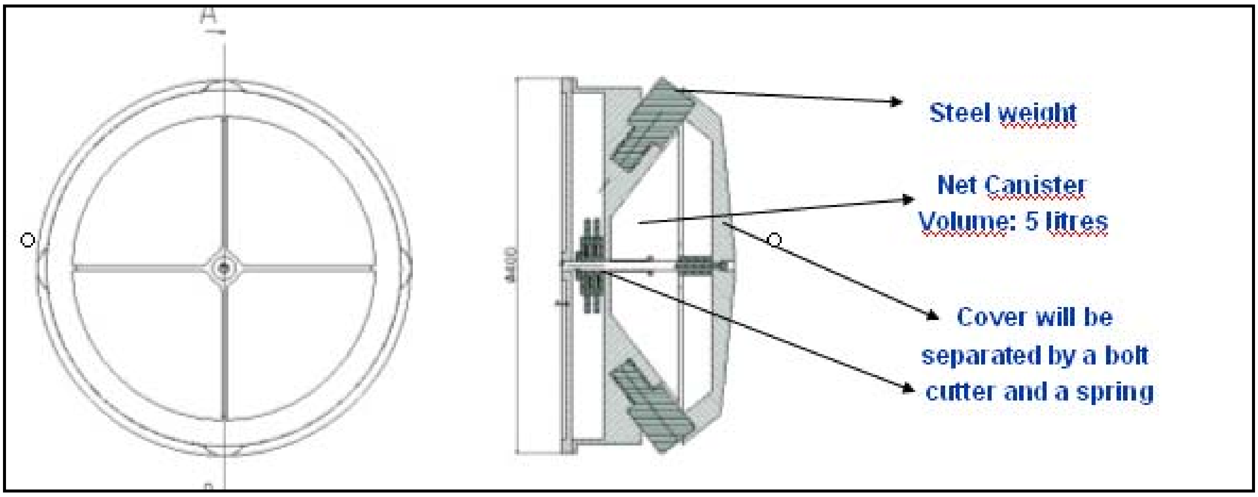

Fig. 5: Net capture Mechanism

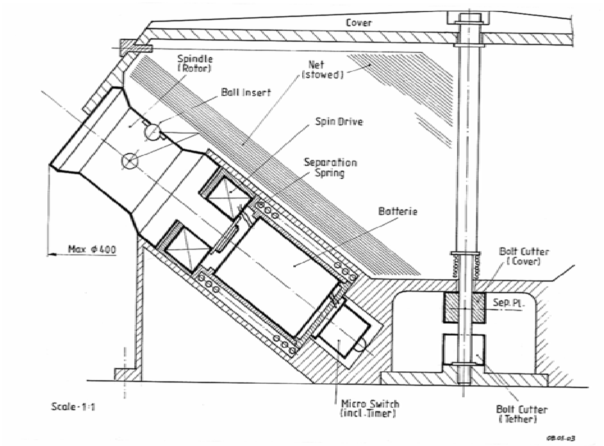

Fig. 6: Net Capture Flying Weight

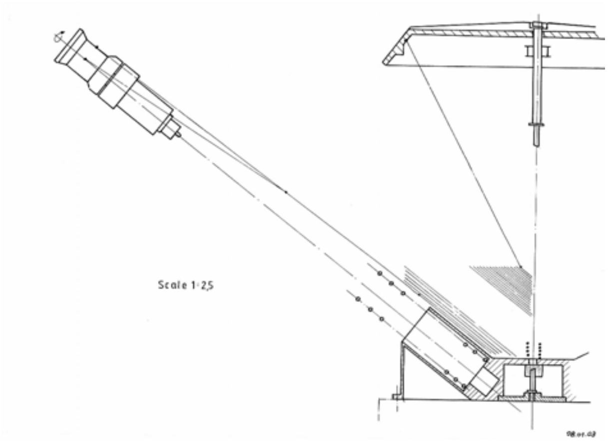

Fig. 7: Flying Weight after Release

Two of the four flying weights contain a mechanism to close the net after covering the target satellite. The elements are:

- Small motor (spin drive)
- Battery
- A micro switch starts a timer, which starts after e. g. 60 sec the motor to roll up the cord between the weights

Tether-Gripper Mechanism

The alternative capture method of the ROGER system will be the Tether-Gripper Mechanism (TGM), as shown in action in fig 8. This mechanism is a free flying element connected by a tether, which includes a power and a communication line. This element consists of a cold gas propulsion system with 12 thrusters of 1 N each, a tank containing of about 4.9 kg nitrogene. The TGM has available 2 stereo cameras and a laser range finder, allowing the ground operator to steer and control the TGM to the special fixation point of the target. On top of the upper platform is mounted the gripper mechanism, a 3-finger mechanism allowing to grip the target element. This 3-finger mechanism is mounted on a telescope arm, which can be deployed of about 60 cm with a joint between the mechanism and the telescope arm. Fig. 10 and fig. 11 are showing the TGM with its dimensions of about 780 mm length and 480 mm in diameter. The TGM has four launch and separation adapters with springs and pyros for the launch phase and the separation for the first mission.

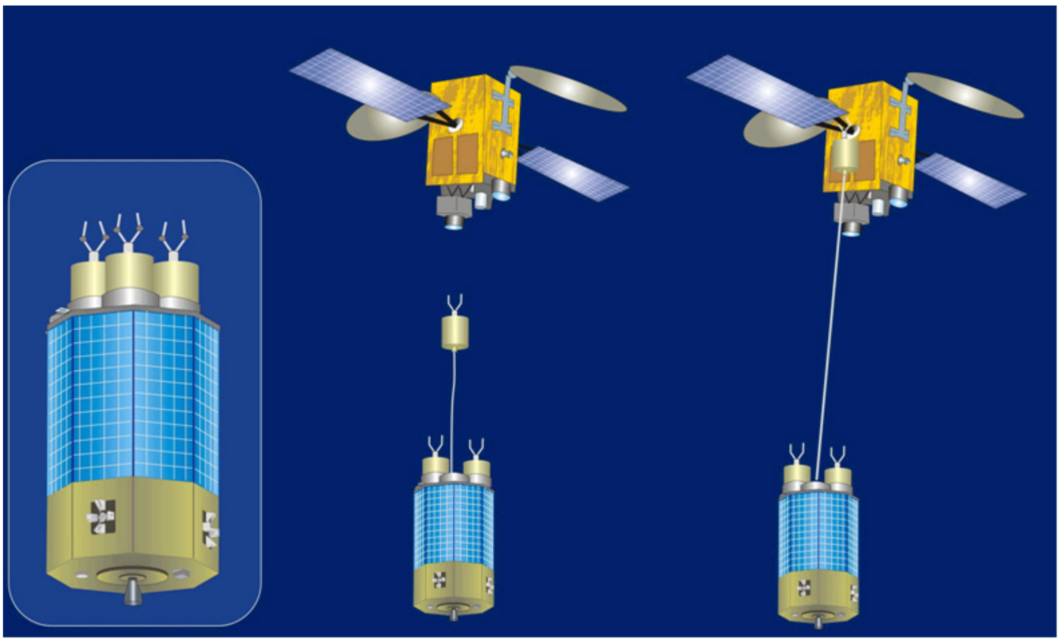
Fig. 8: The Tether-Gripper Mechanism in Action

After the first servicing mission, the TGM will be fixed on the ROGER platform only by pulling and fixation of the tether using the reel and motor below the upper platform. It is foreseen to establish 3 TGMs on ROGER, 2 for the nominal servicing missions and one as back-up system. Each TGM has available a tank with 4.9 kg nitrogene propellant providing a delta-v capability of 75 m/sec. The 1N thrusters of the TGM can accelerate the system such that it achieves a velocity within 3 sec to bring it in a synchronization motion with the outer part (2 m from CoM) of a rotating target.

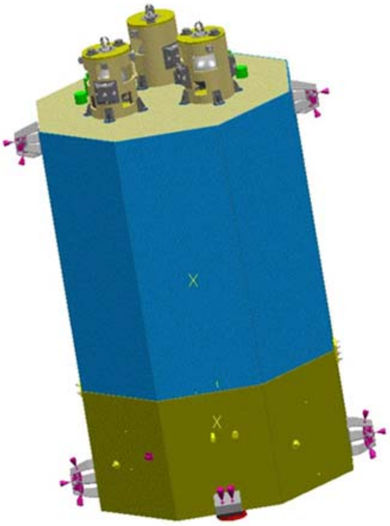

Fig. 9: ROGER with 3 Tether-Gripper Mechanisms

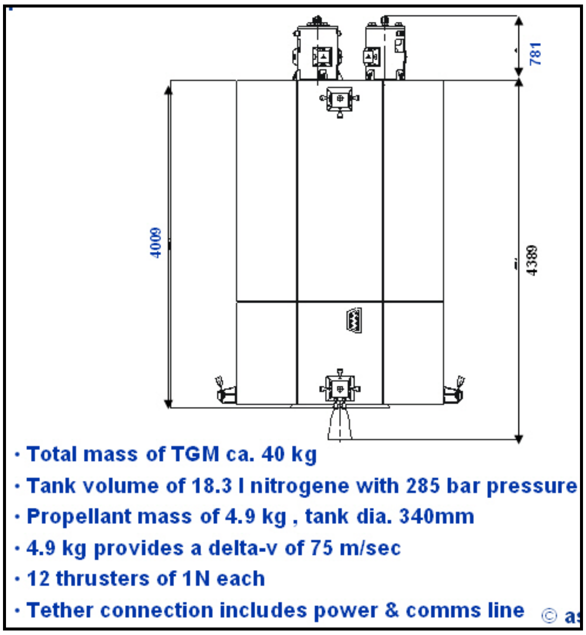

Fig. 10: Parameters of ROGER with TGM

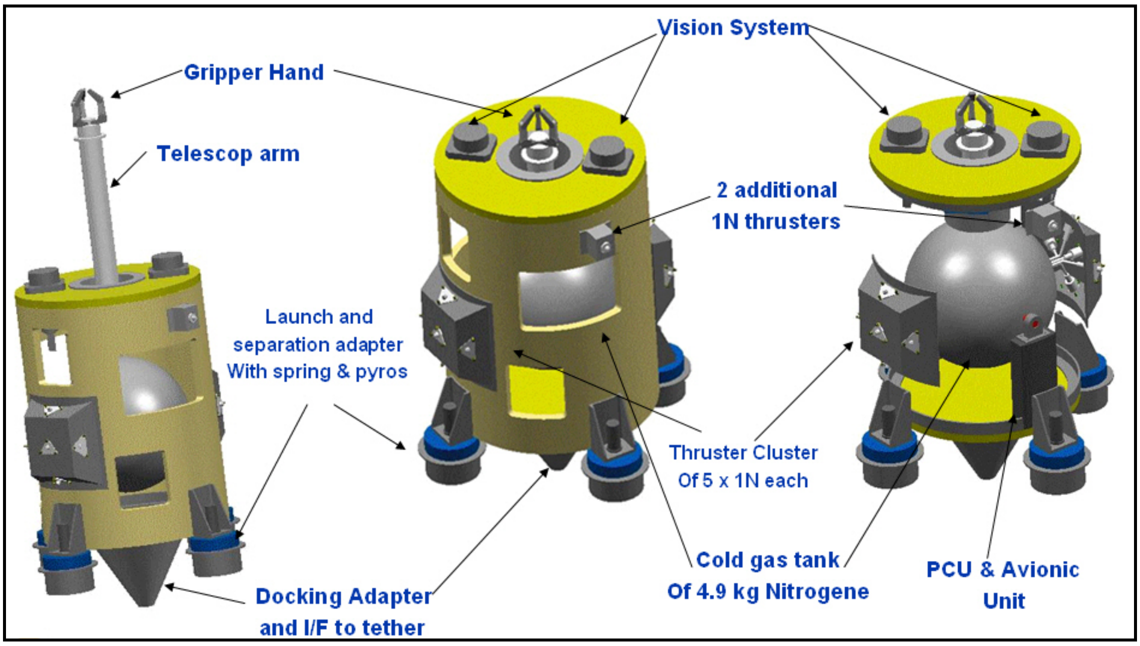

Fig. 11: Tether-Gripper Mechanism

Fig. 12: Combined system

Operational Architecture

The spacecraft is controlled from the central on-board computer (CDMU) by means of different operational states, i.e. GNC modes. Each mission phase is associated with a GNC mode, incorporating individual hardware and software configurations as well as dedicated telemetry formats. The transitions between the individual GNC modes are controlled either board-autonomous based on relevant criteria or are telecommanded from ground control.

The operational GNC mode concept has to take into account the following major mission phases and related objectives:

Far Range operation during ROGER "conventional" free flight phase (GTO, near GEO-drift phases) similar to a “conventional” spacecraft and not directly linked to a target: Ground Station involvement is more related to single TM monitoring and provision of single TC’s for autonomous on-orbit attitude control; Δv manoeuvres calculated on-ground and commanded via TC for autonomous operation. Attitude and orbit control is performed on the basis of absolute attitude and position navigation.

Medium Range approach and operation (Homing & closing phases S1 - S4 and inspection), which is to be performed in a semi-automatic way from ground with TC’s for predefined automatic manoeuvres: Homing Δv commands (S1,S2), Target search and acquisition manoeuvre (S2), v-bar hopping pulses (S2, S3, S4), etc. Automatic combined absolute and target tracking (2 DoF relative) attitude control is performed as well as the transition from absolute position to relative position navigation.

Short Range operation, where together with the relative position control and combined absolute and target tracking (2 DoF relative) attitude control capability the complete relative 6 DoF state is provided from the RVD video-camera system. However, the 6 DoF stereo-camera system based navigation is performed on ground due to the required processing capability. Final target approach incl. target “capture”, composite stabilisation and re-orientation is performed with direct ground involvement. Attitude (absolute or 2 DoF relative) control loops are closed on-board, forces or Δv can be directly commanded from ground via “**ROGER Remote Cockpit**” (TBC) with support from the on-board monitoring and FDIR capabilities.

Tug operation to graveyard orbit and ROGER / target separation will be performed primarily automatic with ground monitoring.

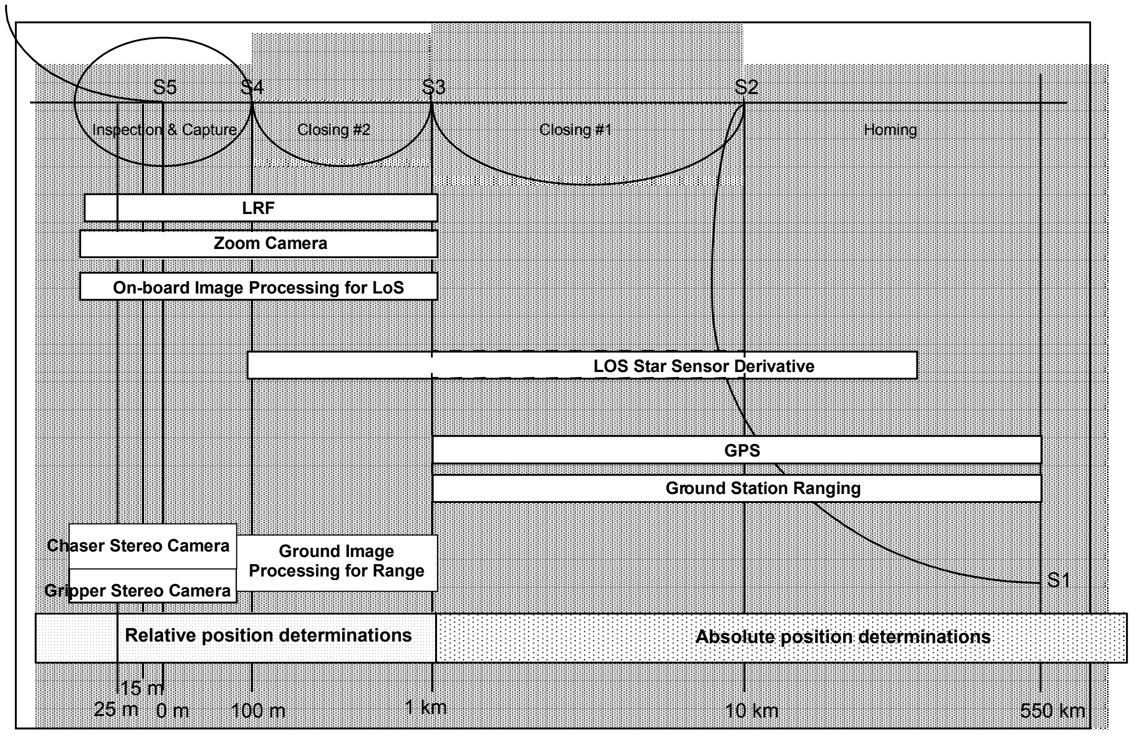

Fig. 13: Approach Scenario

Summary

The study delivered the following main results:

- There are existing several targets useful for orbit clean-up missions
- Relative simple capture mechanism are possible compared to robotic proposals of the past, which require low development effort
- It seems possible to establish a commercial venture for transportation of EOL satellites into graveyard orbit for an acceptable market price

References

1. ROGER Phase A Final Report,
ESA Contract Mo. 15706/01/NL/WK, 2003