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ROGER - Phase A Final Report

Executive Summary

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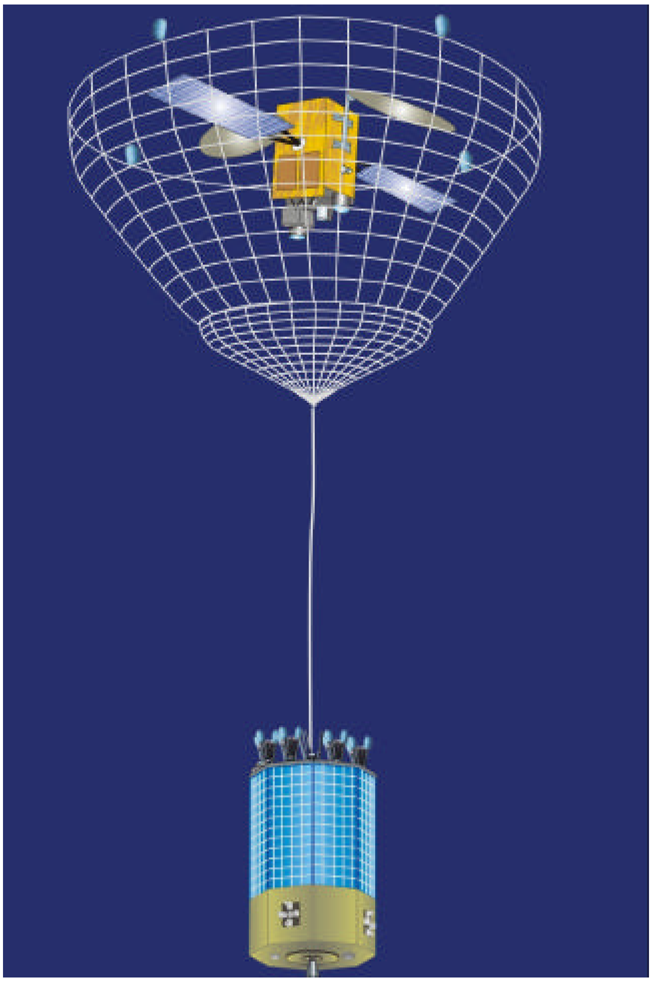

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RObotic **GE**ostationary Orbit **R**estorer

ROGER Phase A

Executive Summary

ESA Contract No.: 15706/01/NL/WK

Astrium SI, Bremen June 2003

LO 11

1. Introduction

The scope of this Final Report is the description of the ROGER System but focusing on the on-orbit flight system.
The status of the GEO and a trend survey will be described as well as the ROGER Scenario, applications and commercial aspects.
The mission scenario, a mission analysis and the operational phases will be described with emphasis on the capture maneuver and the following stabilization and transportation maneuver into the graveyard orbit.
Proposed are two different capture methods and mechanisms, which are very innovativ and described in detail. In the following sections are presented the ROGER platform with its configuration and functional elements.
A subsystem description and its implementation into the Platform design is described.
Additionally are presented the system mass budget and the system power consumption budget.
The ROGER vision system, the robotic elements and the GNC aspects are analysed and described as well as the ground system and the communication aspects.
A ROGER D & D plan and a demonstration mission have been defined and at last are presented some ideas to a commercial implementation.

2. Objectives and Background of a ROGER System

Space Debris Aspects

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.

Retirement Practices

An astonishing result of a recent GEO object survey was that nearly half of all GEO spacecraft launched since 1963 is still listed as operational. In contrast to this, nearly one quarter of these 'operational' payloads is in orbits with at least 2 °inclination. This does not allow for the use of fixed antennas on the ground any more and thus the main advantage of the GEO orbit is lost. The most prominent effect of the luni-solar orbit perturbation is the variance of the orbit inclination over a period of about 53 years It is also known as north-south (N/S) perturbation due to its effect of leading to a north/south deviation of the satellite from its nominal position within the equatorial plane.
Since each object that does not perform station-keeping manoeuvres any more is subject to this type of orbit perturbation, it can be concluded that all objects with a significant orbital inclination have exposed a passive behaviour for a time of several years.

Probably they have reached their end of life and can at best be seen as a hot spare in case of the sudden failure of their successors. This observation is compliant with the fact that geostationary spacecraft used to be simply dumped within their GEO orbit after reaching the end of their useful life. 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 300km above GEO, the Inter Agency Space Debris Coordination Committee (IADC) developed a formula for a graveyard orbit between 245 km and 435km 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.

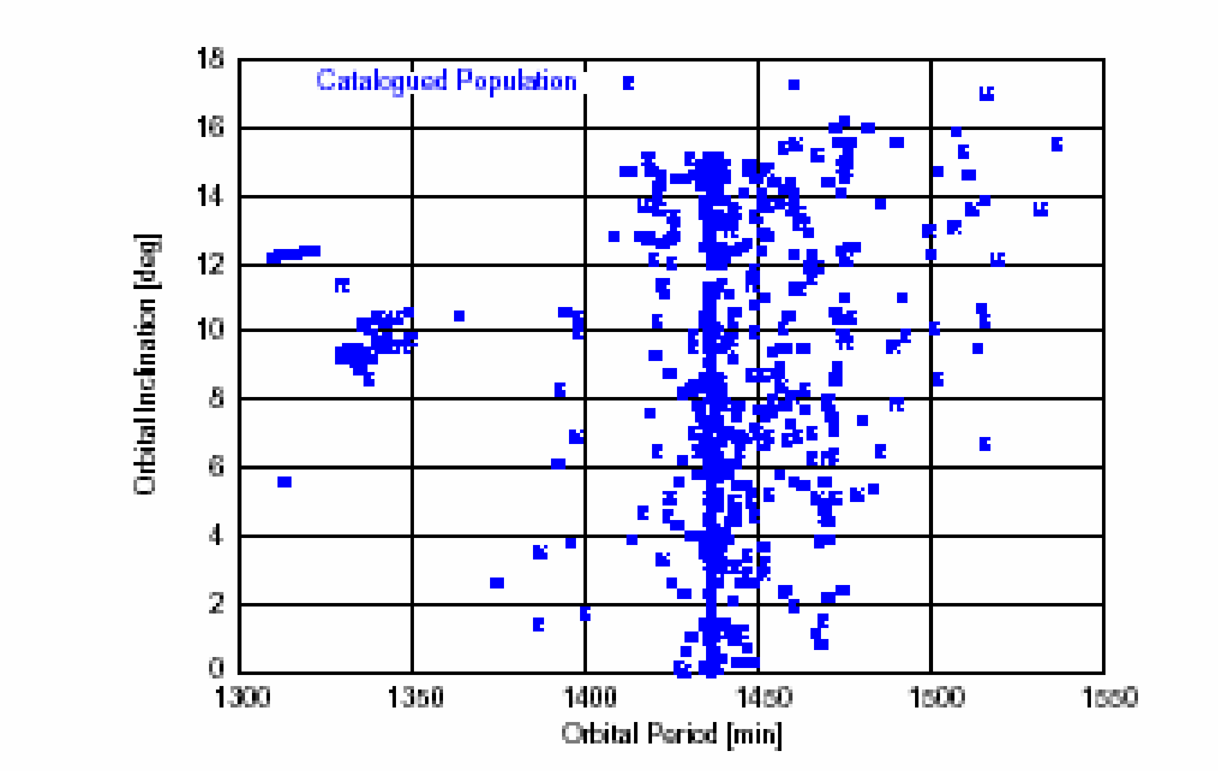


Fig. 2-1: Semi-major axis and inclination of catalogued objects in the GEO vicinity

Controlled (E-W & N-S)	200
Controlled (E-W only)	78
Drift / disposal orbit	382
Libration around 75 deg E	91
Libration around 105 deg W	35
Libration around both points	12
Indeterminate state / no TLEs	91
Others	45
Total:	934

Tab. 2-1:Large GEO Objects – 934 as of 12/02 (by category)

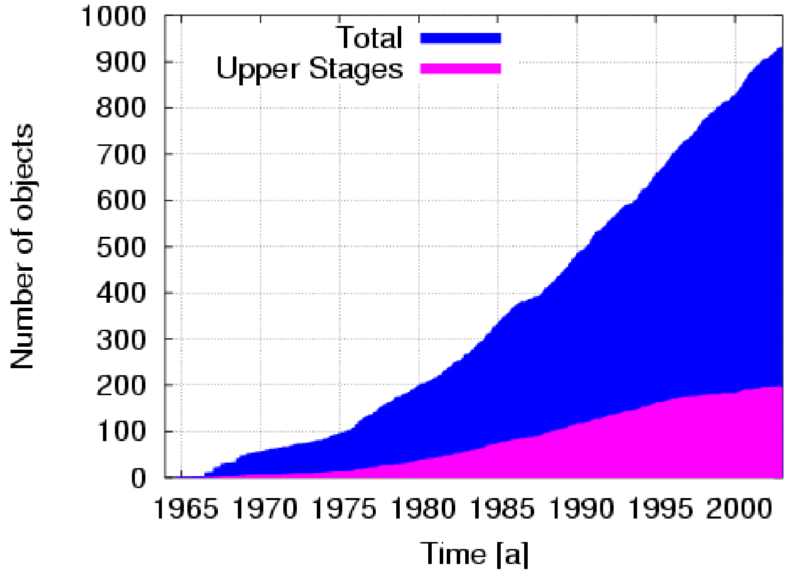


Fig. 2-2: Objects over Time

- Cumulated number of objects steadily increasing(~ 20-30 satellites launched per year)
- Mean payload design life time is approaching 15 years
- Development towards 3-axis stabilized payloads with liquid-fuelled internal Apogee Kick Motors

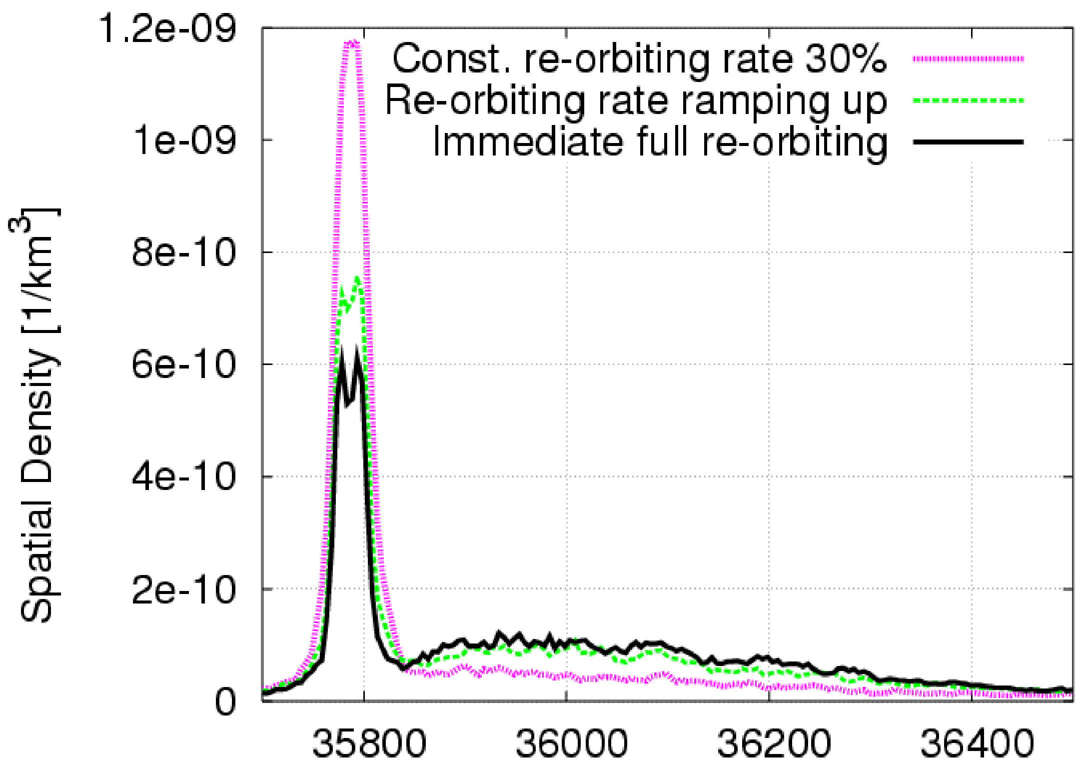


Fig. 2-3: Spatial Density over Altitude

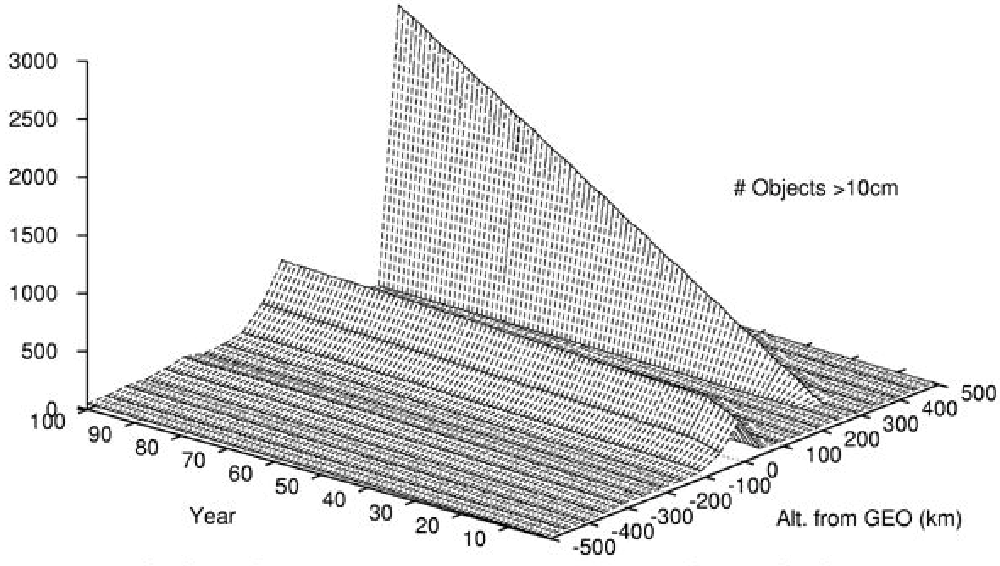


Fig. 2-4: Long-term evolution of a narrow orbital ring near GEO altitude (for the example of a 300 km graveyard orbit) as predicted by the NASA GEO-EVOLVE software

3. ROGER Scenario and Applications

It was clear from the beginning of the study that ROGER applications should not be restricted to the transportation into graveyard of out-of-order drifting satellites, upper stages or debris for which nobody will pay, but also for commercial services, where the satellites operators would be the customers.
Tendencies/Results:

The priority of the operator is going to the extension of the operational life of the satellite as long as possible. This goal includes the use of the entire propellant during the geostationary operation and excludes the autonomous transfer to the graveyard by its own propulsion system. The major problem for the operator is the exact measurement of the residual propellant in the tanks. Therefore only the estimated consumption of propellant is used to decide the end of operation and the transfer to grave yard, if executed. Most of the satellites are transferred into the geostationary orbit by the apogee kick motor where more and more satellites are using the same liquid propellant supply as for the operational phase on orbit. The optimized execution of the apogee injection into the circular geostationary orbit including the transfer to the orbital position could save propellant which could be used for the extension of the mission. The potential extension of operational life including the consumption of the grave yard transfer propellant is in the range of half a year and more. The commercial revenue of this extension is considerable and therefore of high interest for the operators.

Other services as support functions are discussed but of minor value for the operators. Most of the critical subsystems of a satellite are redundant. Therefore one failure of these subsystems will not lead to the loss of the satellite. The first evaluation of the failure cases indicates a low number of total loss of satellites due to failures(s) and the low probability of repair potential and a high risk of damages.
The major arguments during the former GSV discussions have been based on the repair capabilities for the failure cases of TVSAT (initial phase) and OLYMPUS (during operations) which requires specific support and even high sophisticated services to enable the (further) operation of the satel-

lite. The dedicated features of the vehicle especially the complex robotic tool system and specific approach scenarios and the soft capture features result in high development costs for the vehicle.

The recommendations of the satellite operator are now going to the hard capture and transport of defect / deactivated targets. This fact reduces the requirements for the system decisively.

The interest of the insurance seems to be the complement to the operator aspects. The transfer service is of no interest, while the repair or refuelling aspects seem to be recommended by this potential customer. Especially the refuelling of stranded satellites is of importance for the insurances because mostly the entire mission of the satellite is assured including the operational time on orbit with decreasing value of the residual revenue. Therefore a total loss during the initial phase of a satellite is expensive.
A few satellites are also insured against the loss of market share due to the early loss satellite. The supposed interest for inspection of defect satellites is of minor interest for the interrogated insurance because the reason for the loss of satellite is more important for the satellite designer than for the insurance except specific clauses are contracted, which exclude the liability for these specific cases. Here the interest of the insurance company exists to have an independent tool for inspection depending on the amount of money to be paid for the specific case in relation to the cost for the inspection. The initial insurance value for satellites is in the range of 250 Mio $ with exceptions to 400 Mio $. If the credibility of the described failure reason is questionable a few percent of the insurance value could be spend for the better knowledge of the situation.

International Organisation

The contact to the international organisation has not yet fruitful results, but the interest for the cleaning of the geostationary orbit will be one major target of this organisation. Especially the critical sources for debris like the retired satellites and the upper stages will be objects to be transferred to save orbits. The idea of a financial pool for this purpose managed by this organization and supplied by the participating countries could be the initial step to be interested in the specific vehicle with the required capabilities, but the available information show that the UN organization especially the United Nations Office for Outer Space Affairs (OOSA) is not interested in any financial engagement.

Financial aspects

Basic calculations

Starting the first rough estimation for the costs of a ROGER vehicle for the development, manufacturing, launch and operations (~ 5 years) a value of about 200 Mio $ US was determined based on the experience of the SIRE development assessment. The recurring cost share is assessed in the range of 150 M$ US including the launch and roughly the operations costs.
The development (and launch) costs of the first Roger vehicle can conceivably be covered by an ESA budget, but ESA would not operate the commercial ROGER company. Thus, if a Roger company is to be commercially viable, it must earn enough to pay for initial setup including the necessary capital expenditures, which could easily reach 20 M$ or more, ultimately enough to replace the first Roger vehicle with another one when it reaches its end of life, and finally, some profit. The ROGER vehicle is designed for 20 grave yard missions and ~ 10 inspections as service potential of one ROGER mission.

The following commercial model can be derived taking into account the figures discussed with the operators about the income of 2 Mio $ per transponder per year and cost of 1-2 Mio $ for the operations of a typical communication satellite per year with 24 transponders for a small S/C and 50 transponders for a large S/C.
For a set of 30 operational transponders as average and a prolongation of operational time of about 6 months using the residual propellant a benefit of more than 25 Mio $ can be expected. Compared to the transfer cost of 10 Mio $ for re-orbiting a residual benefit of more than 15 Mio $ will remain for the operational company. The higher share of benefit shall be balanced against the risk of earlier EOL or the loss of S/C during the additional operational time for the operators.

The first baseline calculation leads to the following prices:

20 grave yard missions	per 10 Mio$	=	200 Mio $
10 inspections	per 2 Mio $	=	20 Mio $.

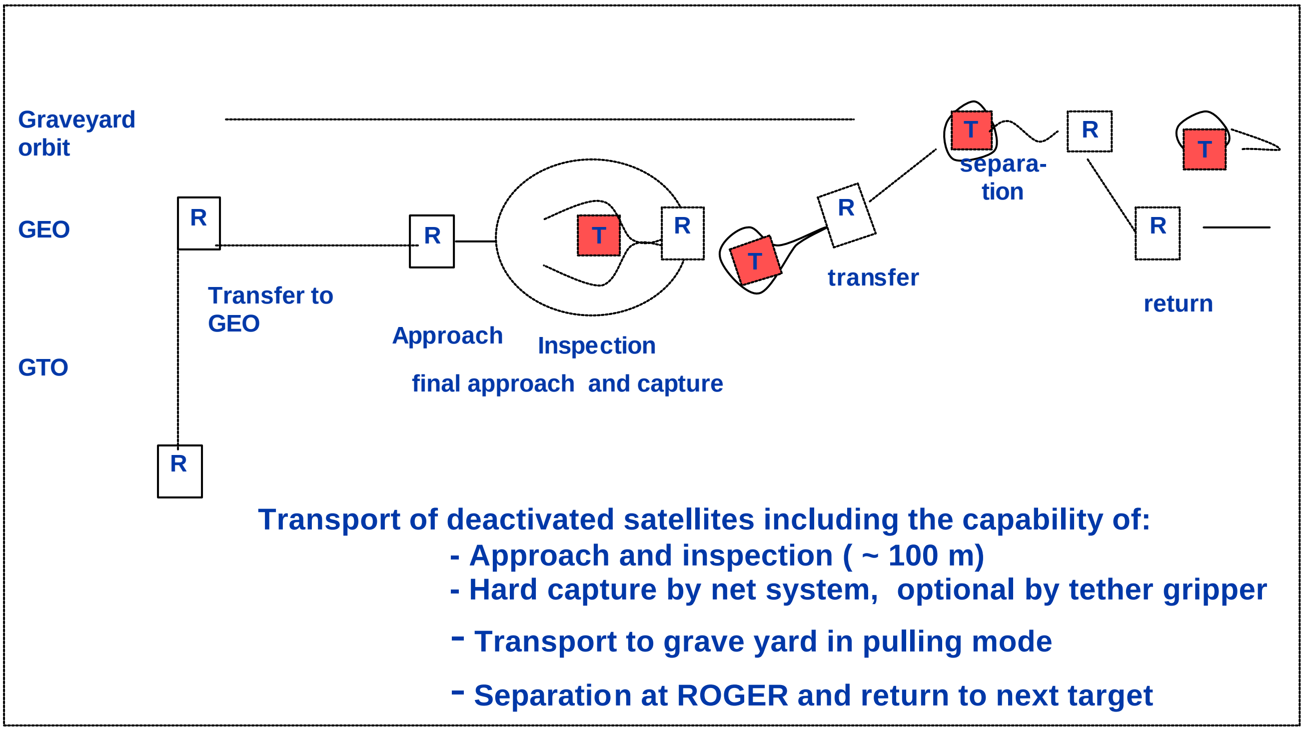


Fig. 3-1: Selected reference scenario

4. ROGER System Definition

4.1 Mission Description

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.

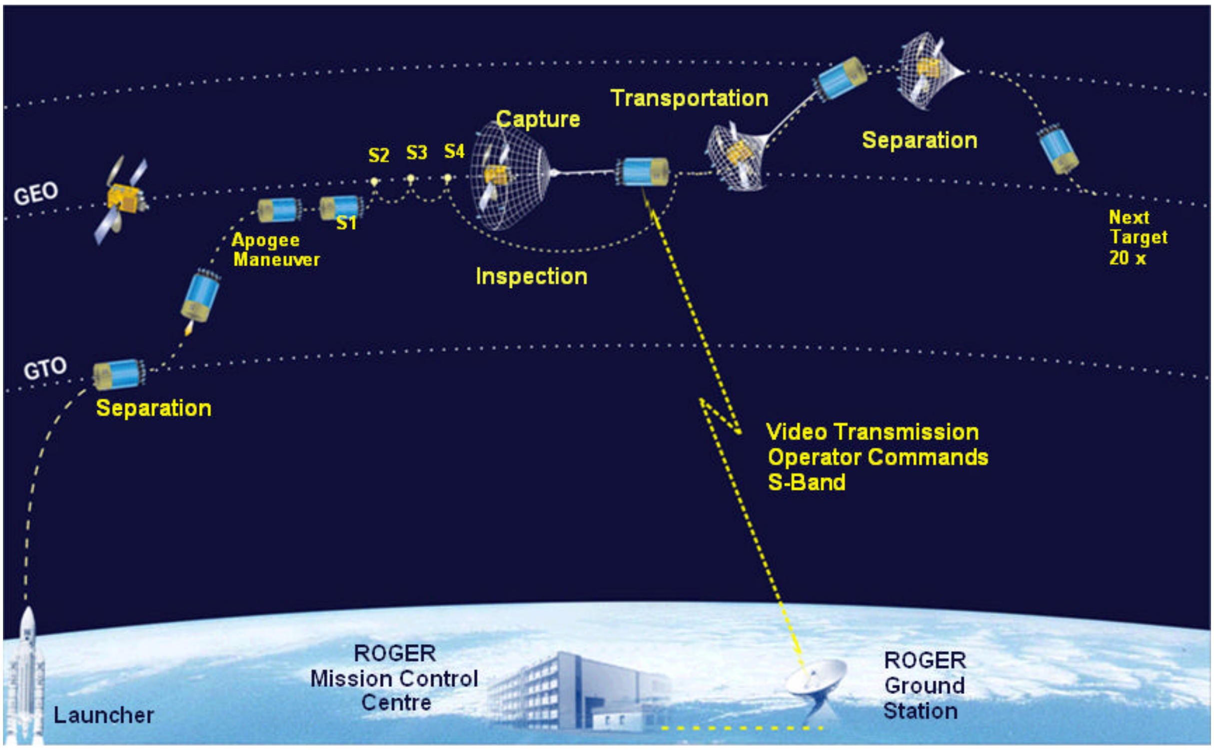


Fig. 4-1: Mission Scenario

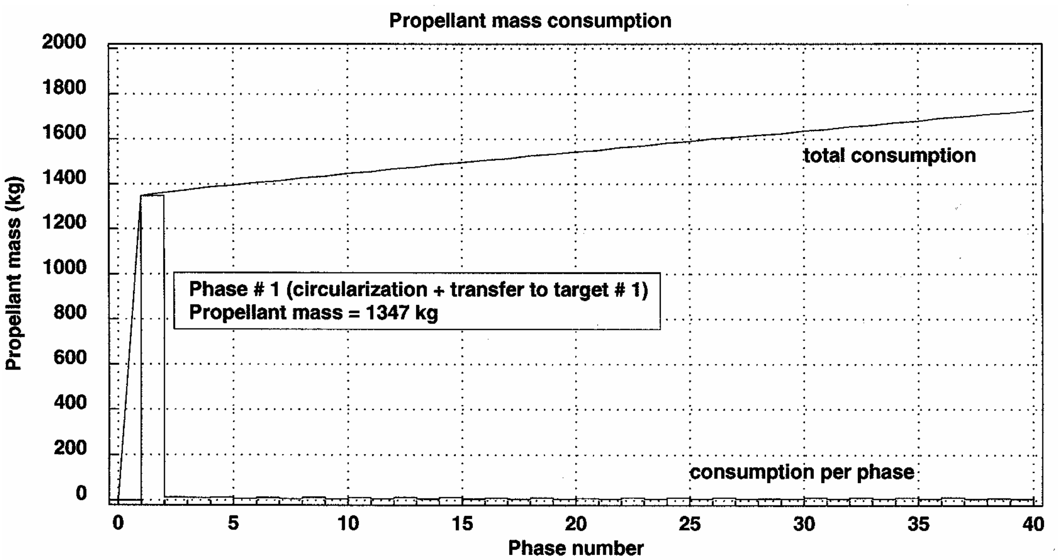
It will then follow a closing maneuver with 2 thrust impulses to reach the point S3 about 1 km away from the target. After a waiting phase the next closing maneuver will lead ROGER to point S4 about 100 m away from the target. After the observation and pose determination ,ROGER will perform a maneuver 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. 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.

The table below shows the optimization results of graveyard transportation of 60 satellites, which leads to 3 reference missions with the documented transportation ranking.

Mission # 1	Mission # 2	Mission # 3	
COSPAR	COSPAR	COSPAR	target #
1992-032A	1994-034A	1994-034A	1
1995-064A	1993-066A	1993-066A	2
1996-007A	1993-048A	1993-078A	3
1998-024B	1993-078A	1996-002B	4
1991-075A	1994-065A	1995-069A	5
1992-010B	1995-001A	1992-027A	6
1994-065B	1994-064A	1992-057A	7
1995-016B	1996-044B	1992-032A	8
1994-055A	1995-069A	1992-060A	9
1992-066A	1998-063B	1991-037A	10
1997-049B	1998-056A	1991-018A	11
1995-011B	1994-047A	1991-003B	12
1991-084B	1996-040A	1988-018A	13
1991-083A	1996-030B	1989-067A	14
1993-073B	1998-044A	1985-109B	15
1992-021B	1996-063A	1985-025A	16
1995-054D	1995-064A	1983-059B	17
1993-039A	1996-007A	1982-082A	18
1991-054B	1997-021A	1981-119A	19
1991-001A	1997-027A	1980-104E	20

Tab. 4-1: Listing of the three Reference Missions

Mission #2:



For each target :
• rendezvous transfer phase
•graveyard transfer phase

Fig. 4-2: Propellant Mass consumption for Mission 2

4.2 Flight System description

The ROGER mission consists after the separation from the launcher of the following main elements, which are shown in Fig. 4-3: Main Elements of the Mission.The satellite platform with a total mass (BOL) of 3 500 kg and a propellant mass of about 2 700 kg, with dimensions of 4 m length and a hectogonal shape with a diameter of 2.5 m, will accommodate the capture mec hanisms, which are shown beside. There are proposed two different capture mechanisms:

- 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.

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 10m x 10m to 20m x 20m 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.

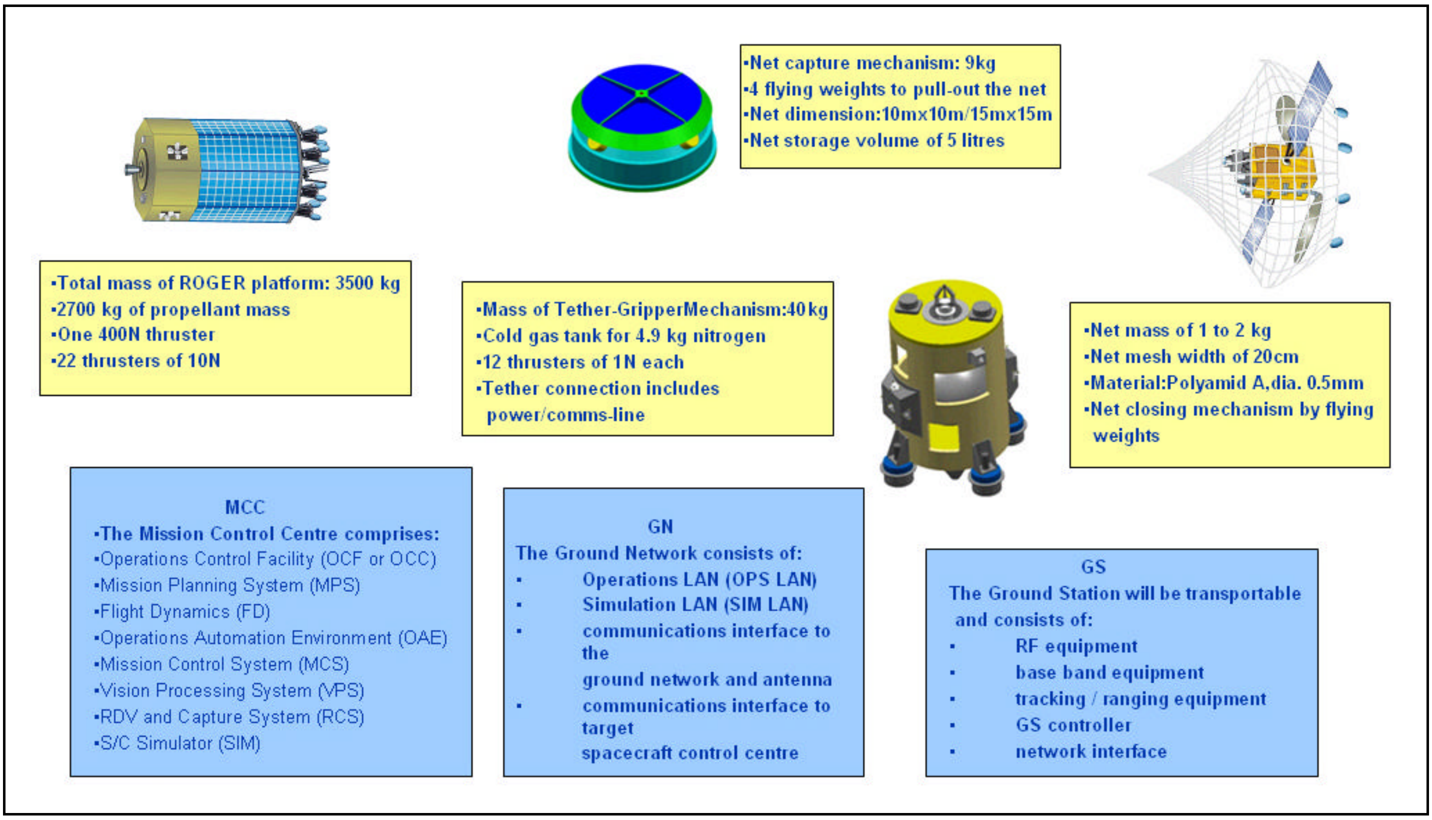


Fig. 4-3: Main Elements of the Mission

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. 4-5 and Fig. 4-6 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 10m x 10m or 15m x 15m 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. 4-7, 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.

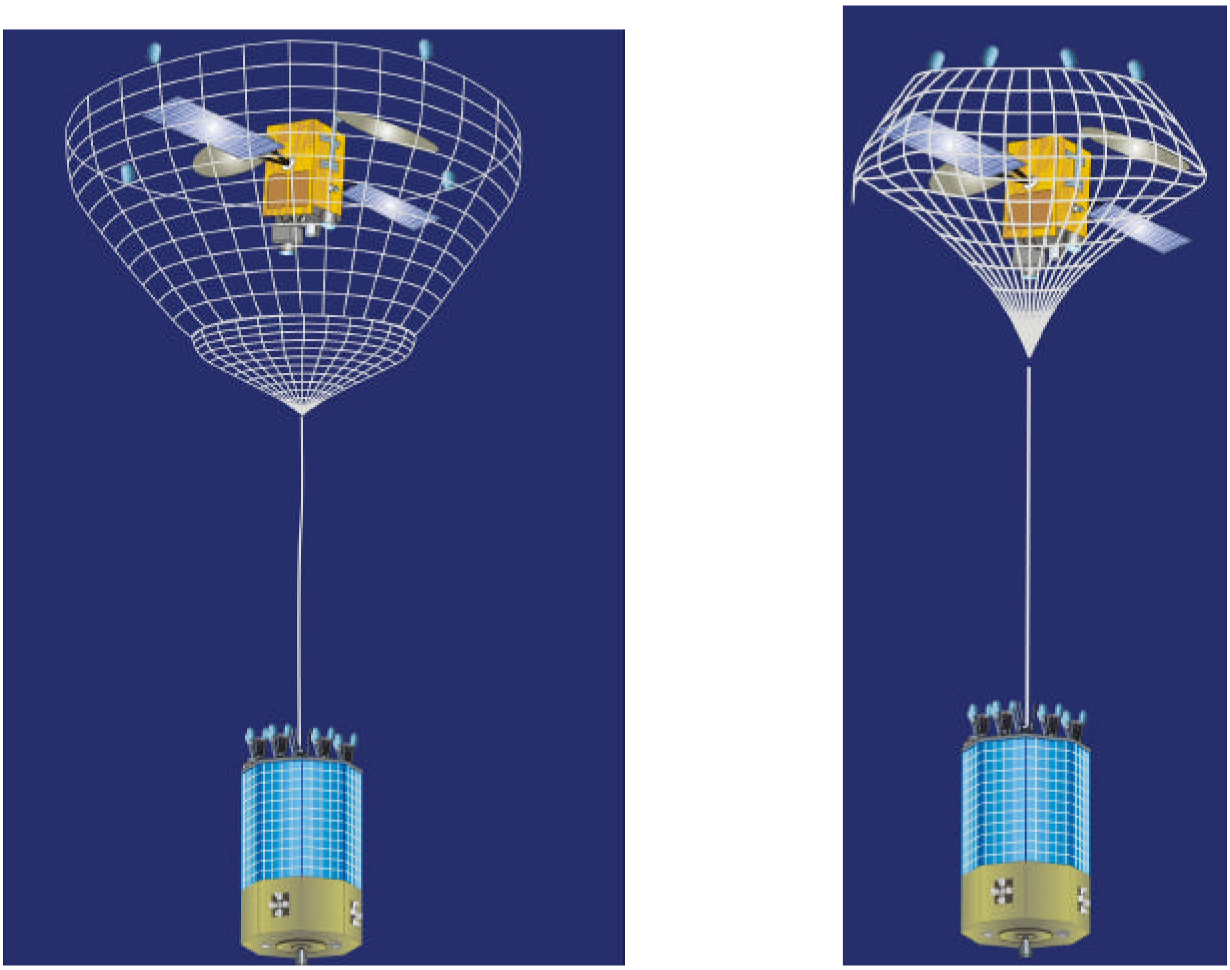


Fig. 4-4: Net Capture Mechanism Deployed

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 (10m x 10m or 15m x 15m or more) for different satellite sizes**
- **Tether of max. 60m length and 1mm dia. 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)**

Tab. 4-2: Net Capture Mechanism Elements

Net Capture Parameter

Net dimension:10m x 10m (15m x 15m)
Mesh width: 20cm x 20cm
Material: Polyamid A; diameter: 0.5 mm
Net mass: ~1.0Kg; 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. 4-5: Net Capture System

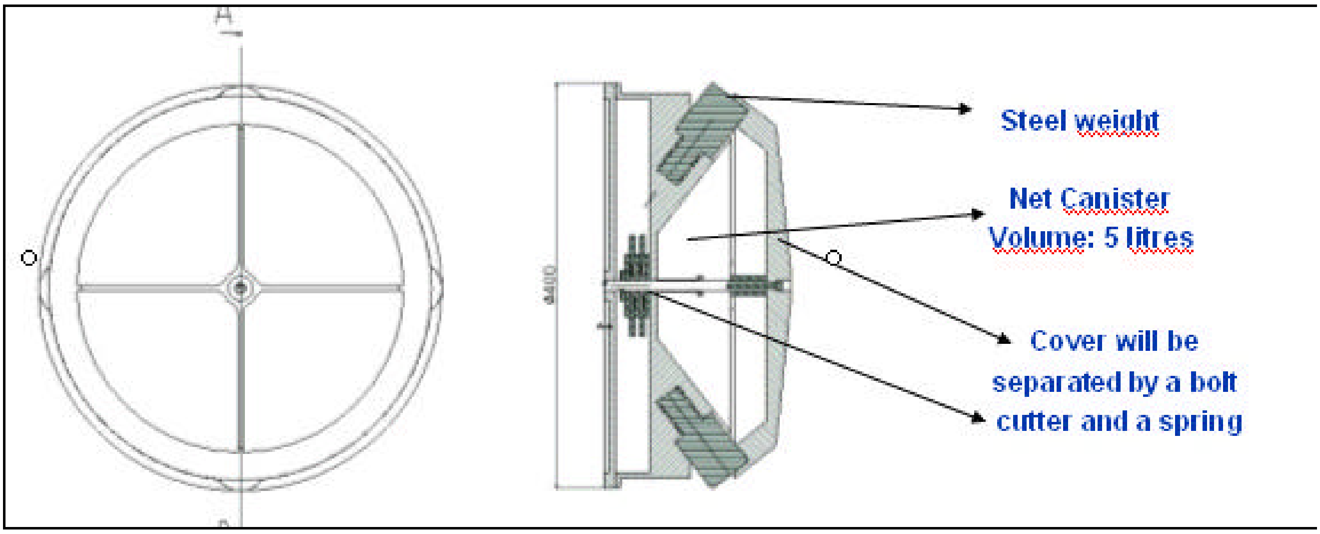


Fig. 4-6: Net capture Mechanism drawing

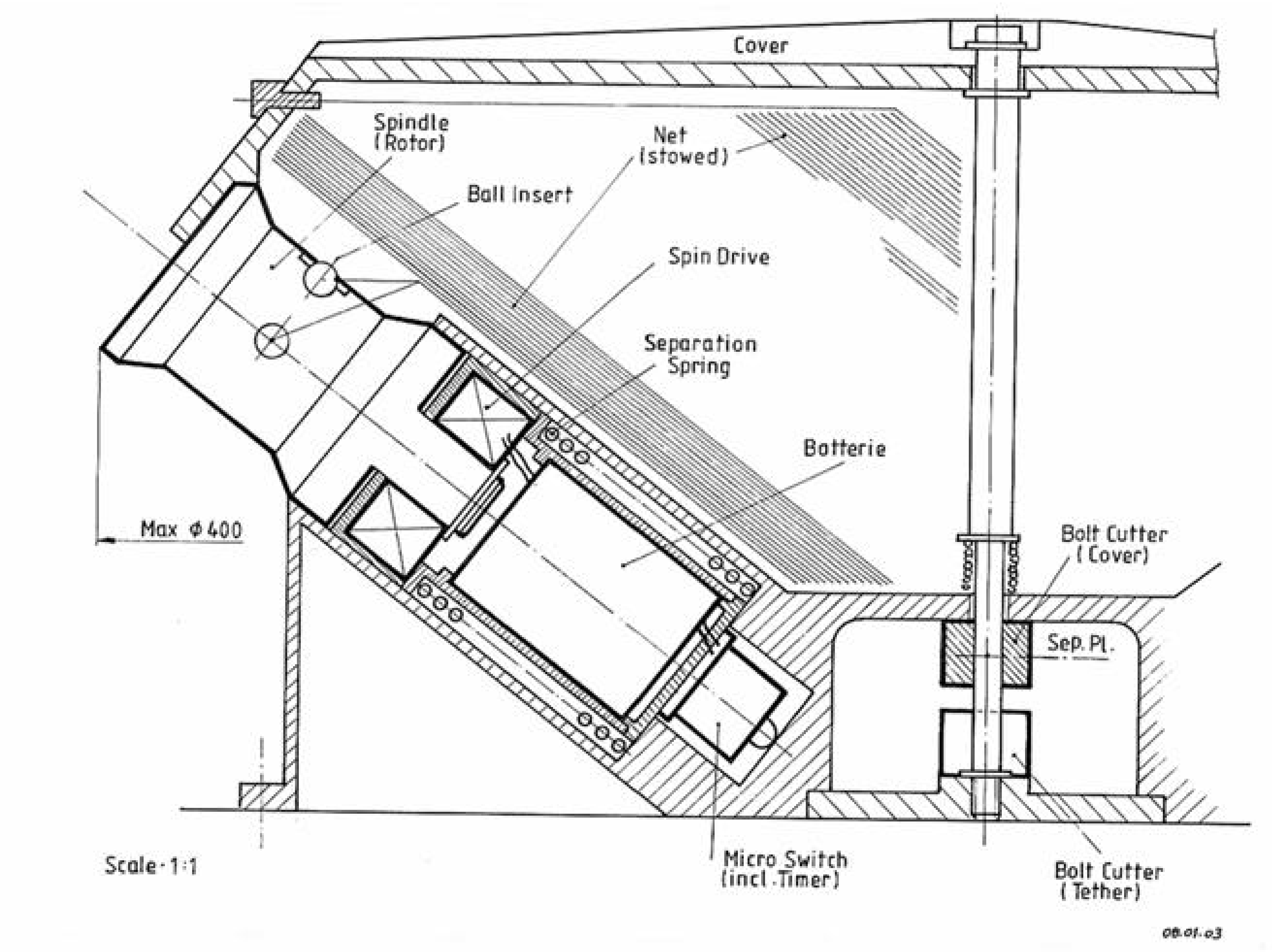


Fig. 4-7: Flying Weight containing a Net Closing Mechanism

Two of the four flying weights contains 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**

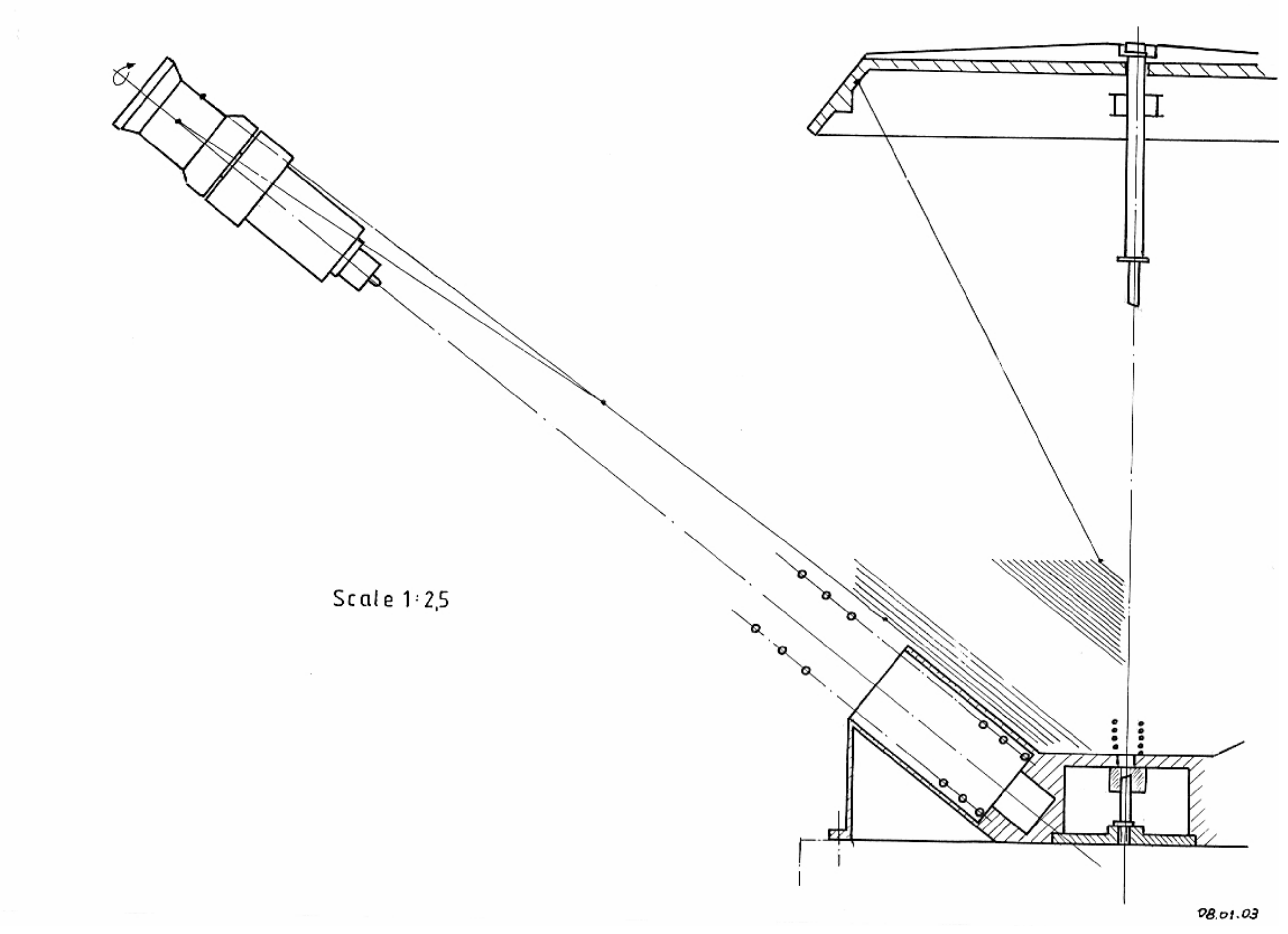


Fig. 4-8: Flying Weight with Net Closure Mechanism after release

Tether-Gripper Mechanism

The alternative capture method of the ROGER system will be the Tether-Gripper Mechanism (TGM), as shown in action in Fig. 4-9. 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 1N 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 60cm with a joint between the mechanism and the telescope arm.
Fig. 4-12 and Fig. 4-13 are showing the TGM with its dimensions of about 780mm length and 480mm 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.
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, see Fig. 4-14.
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 (2m from CoM) of a rotating target.

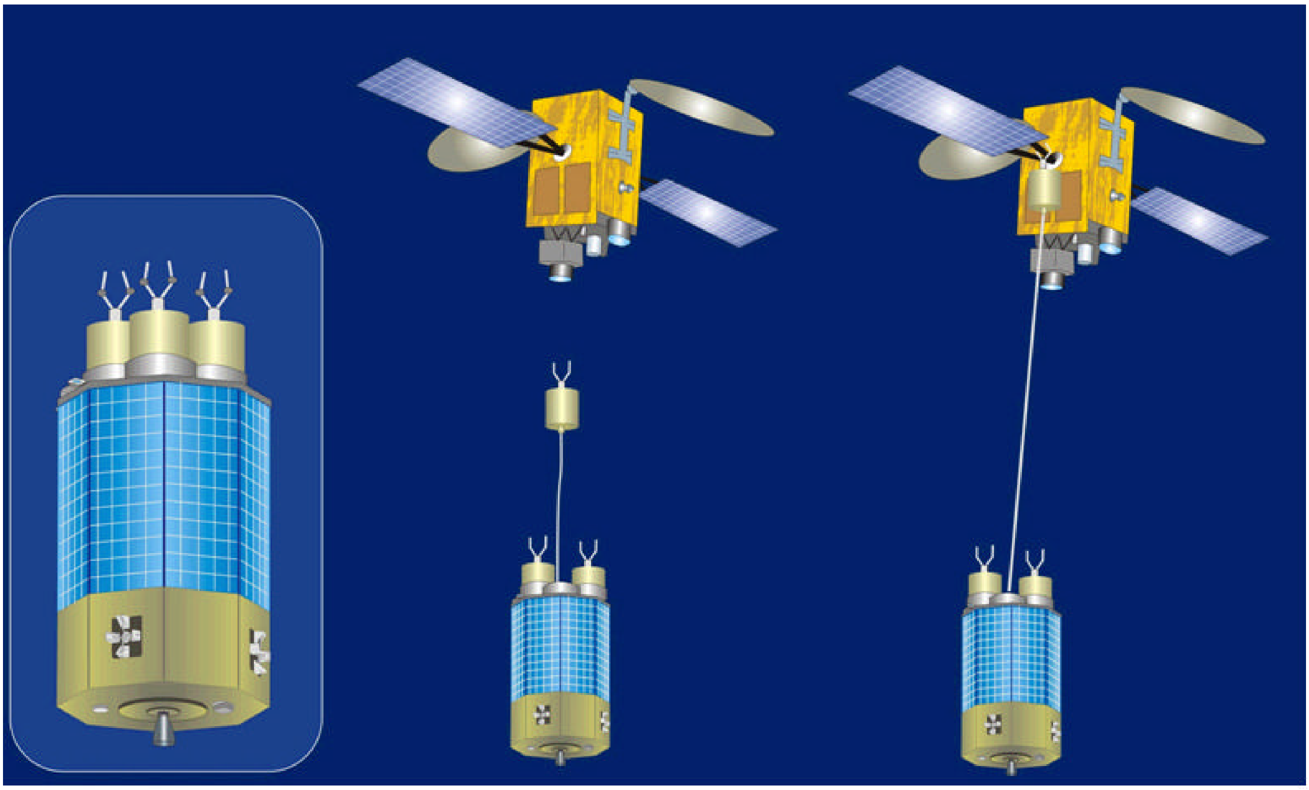


Fig. 4-9: The Tether-Gripper Mechanism in Action

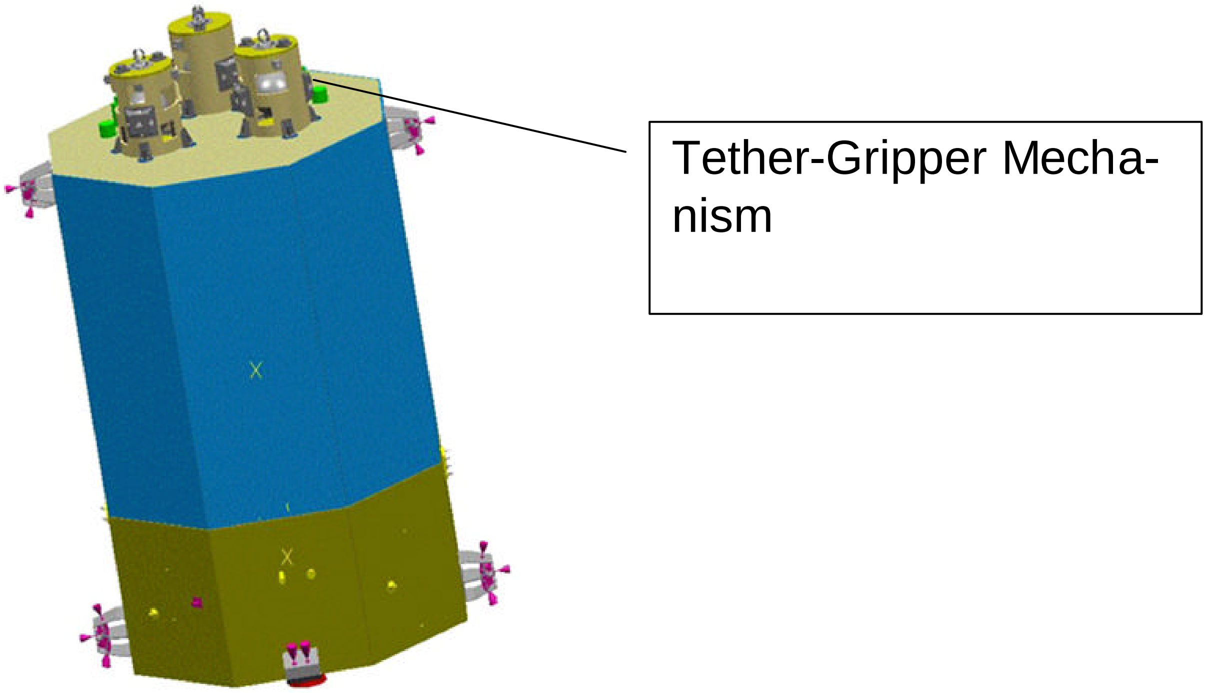


Fig. 4-10: ROGER with three Tether-Gripper Mechanisms

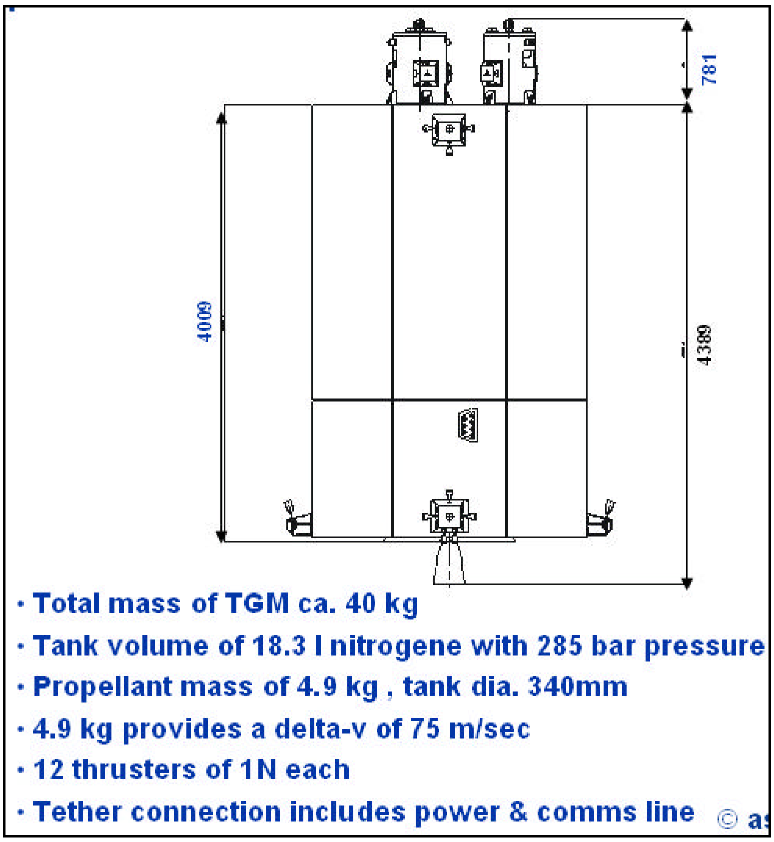


Fig. 4-11: **Drawing of TGM on ROGER and the main Parameters**

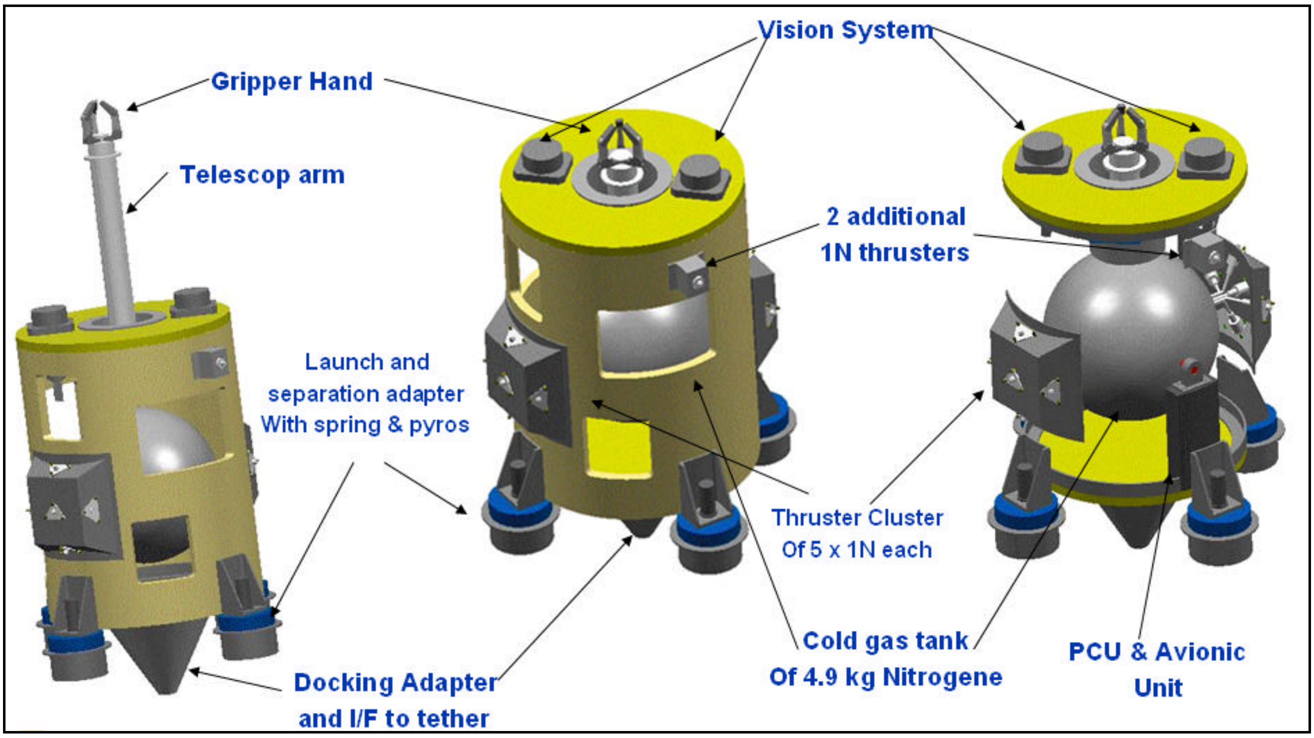


Fig. 4-12: 3-D View of the Tether-Gripper Mechanism

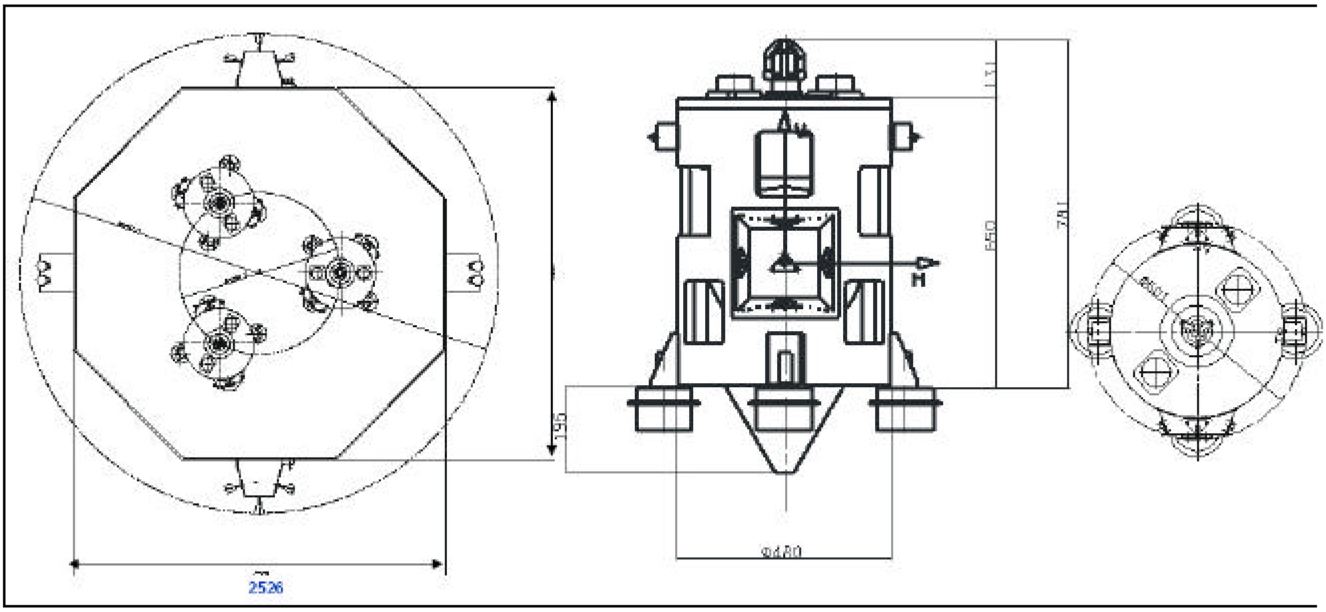


Fig. 4-13: Drawing of the Tether-Gripper Mechanism

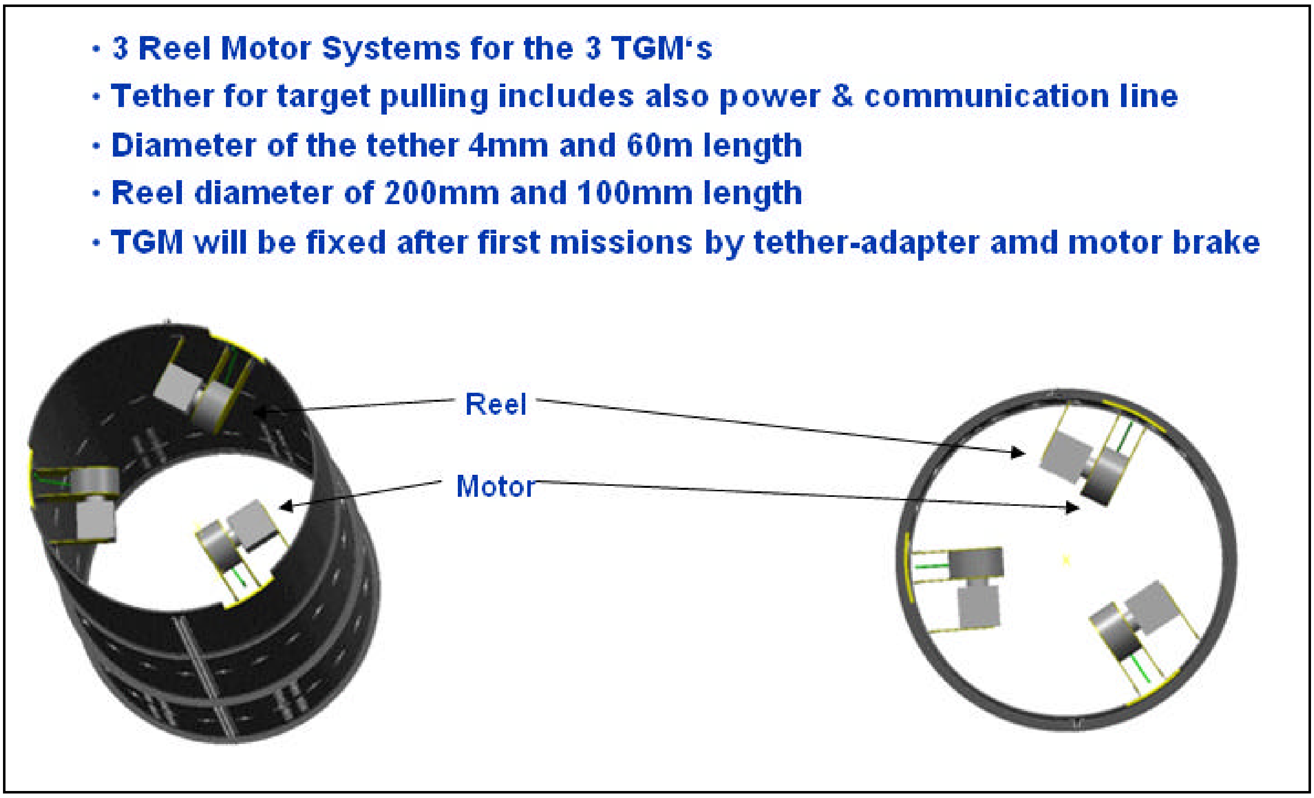
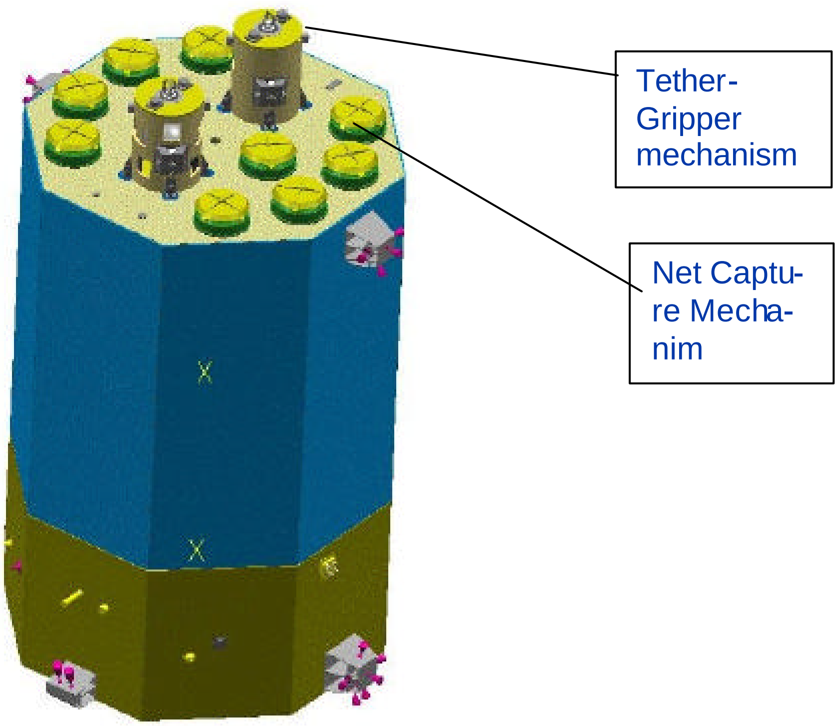


Fig. 4-14: View of the 3 Reel-Motor Systems for the 3 TGM's

Satellite Platform

The proposed satellite platform, as shown in Fig. 4-15, is a derivative of a former very detailed designed Astrium platform, with detailed structural and thermal analysis. Most of the foreseen and in following section described 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. Two additional thrusters cluster 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.



- **A mixture could be the utility of 2 TGM's (100 Kg) and 10 Net Capture Mechanisms (100 Kg)**
- **A mixture would enhance the operational flexibility and reduce the system risk**

Fig. 4-15: View of the ROGER Platform

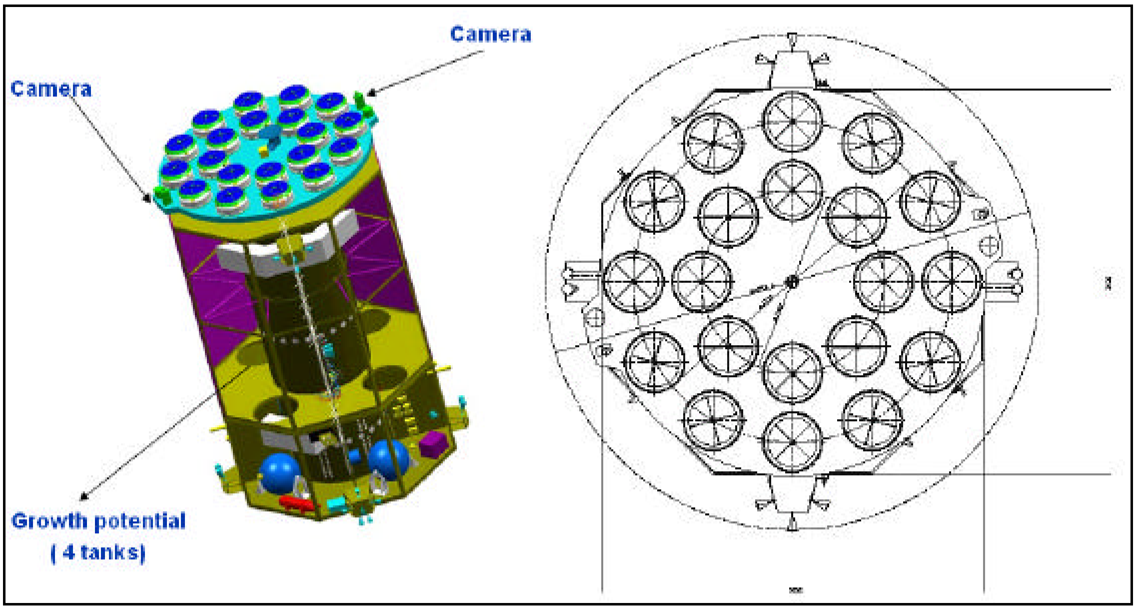


Fig. 4-16: ROGER Platform with the upper Payload Plate

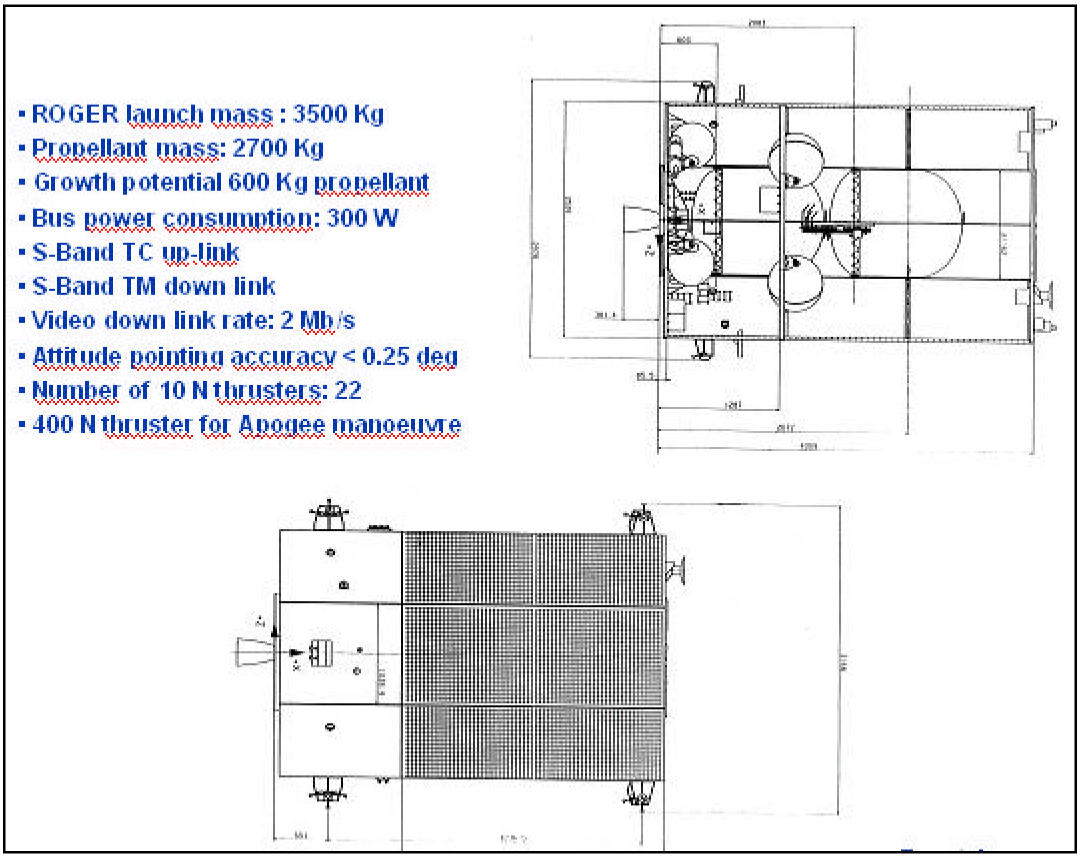


Fig. 4-17: ROGER Platform and its Main Parameters

The following table 4-3 lists the vision system equipment in relation to their vision function and range to the target.
Fig. 4-18 and 4-19 are illustrating the approach scenario and the related sensor application.

VISION SYSTEM	RANGE	VISION SENSOR	VISION FUNCTION	GROUND FUNCTION
ROGER Vehicle	S3 => S5 1000 m to ~25 m	Zoom Camera + Laser Range Finder	Range (<300m), LOS 1-2hz	Bearing, Target pose, Target rotation
	~30 m to ~15 m	Stereo cameras(*)	range, bearing 2hz	Target rotation rate
Gripper	15 m => 0.1 m	Stereo cameras(*)	range, LOS 5hz	Bearing, Target pose

(*) Including illumination

Tab. 4-3: Proposed ROGER Vision System Configuration

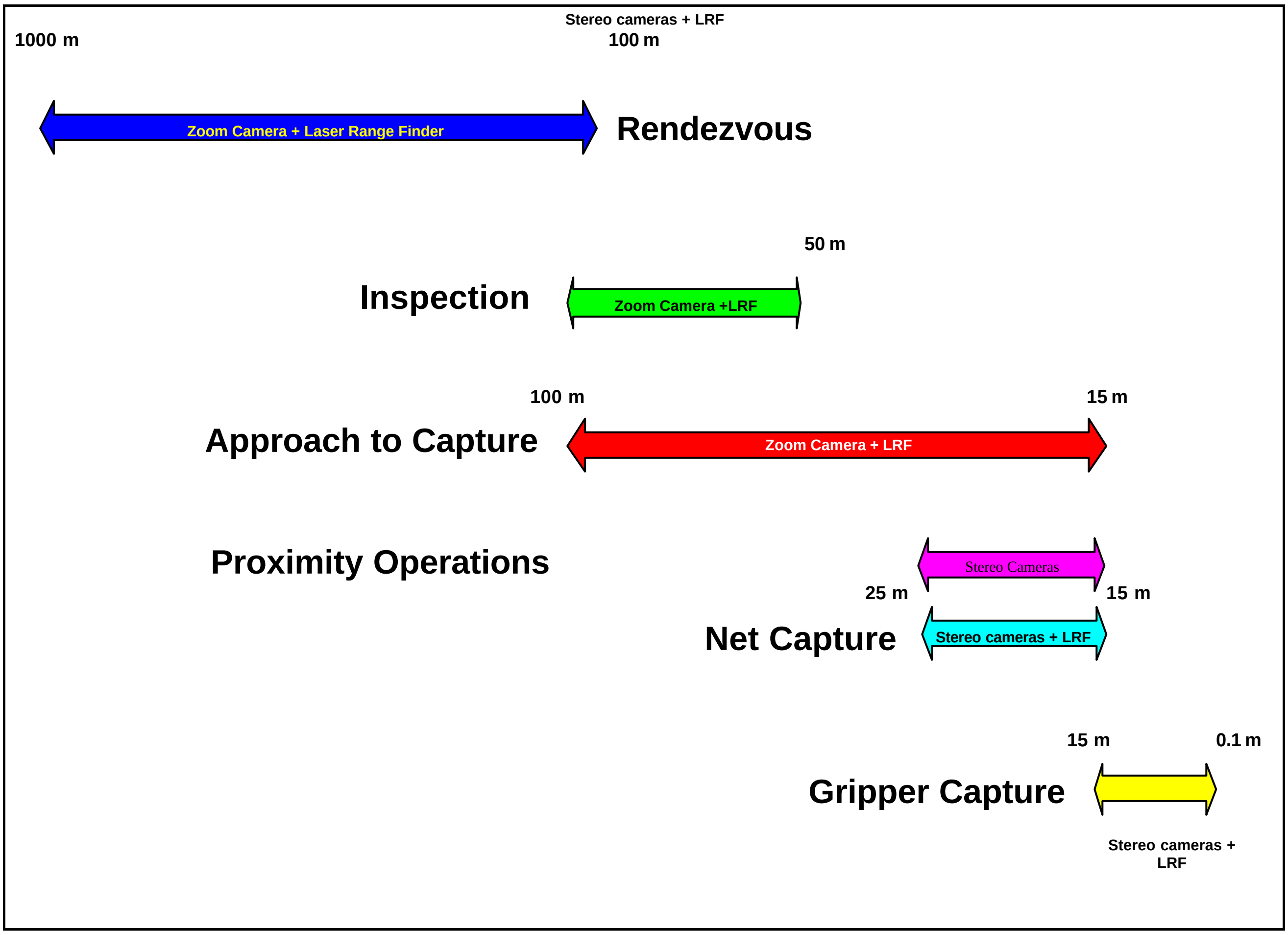


Fig. 4-18: Mission Phases and the related Sensors

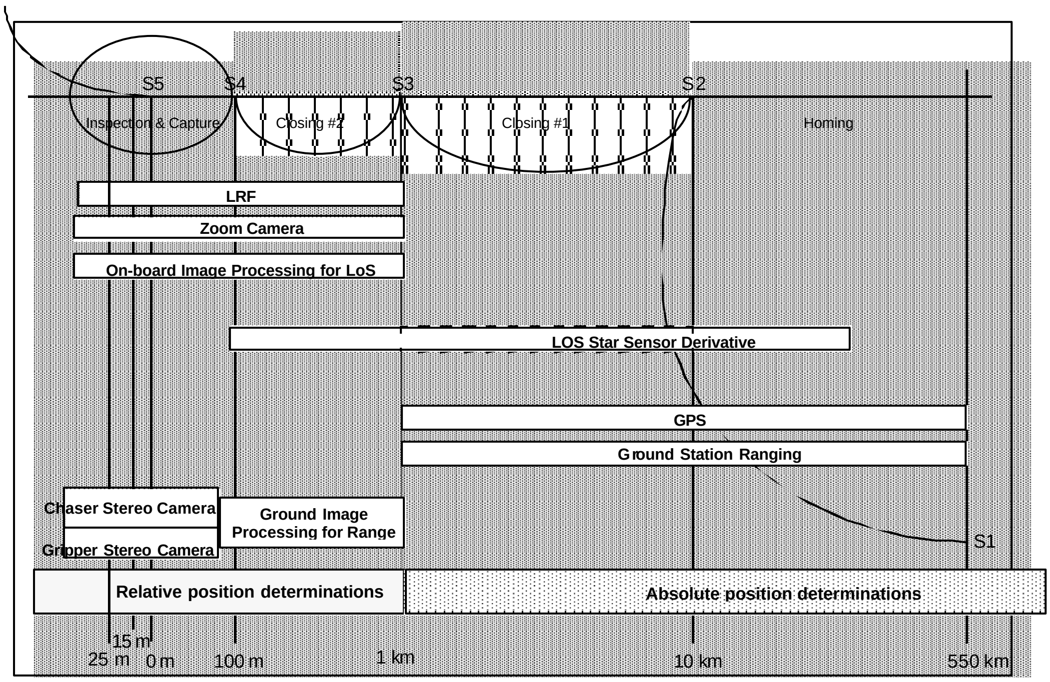


Fig. 4-19: Roger Target Approach Scenario

The fig. 4-20 below depicts the GNC architecture for ROGER as result of a detailed functional analysis. The Range- and LOS-Sensor Assembly are elements of the vision system, see description below.

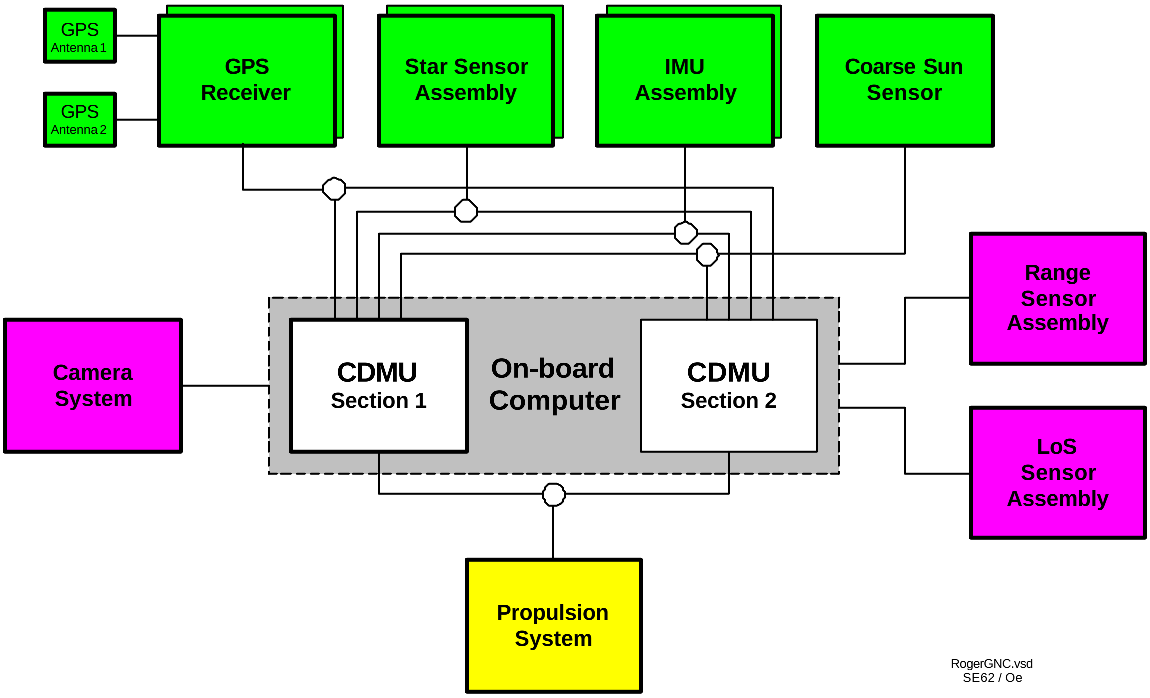


Fig. 4-20: Roger GNC Hardware Architecture

4.3 Ground System Description

The ground segment will have the responsibility for controlling the rendez-vous, capture and transfer of the target to the graveyard orbit. To support these operations, the ground segment will provide a Mission Control Centre equipped with a Mission Control System (MCS), Flight Dynamics (FD) tools, a Vision Processing System (VPS) and a Rendez-vous and Capture System (RCS) as key components during the interactive part of the mission. In addition, a Mission Analysis System will allow the off-line preparation and planning of the ROGER missions. An Operations Automation Environment (OAE) is foreseen for the preparation and the automatic execution of ground operation procedures.

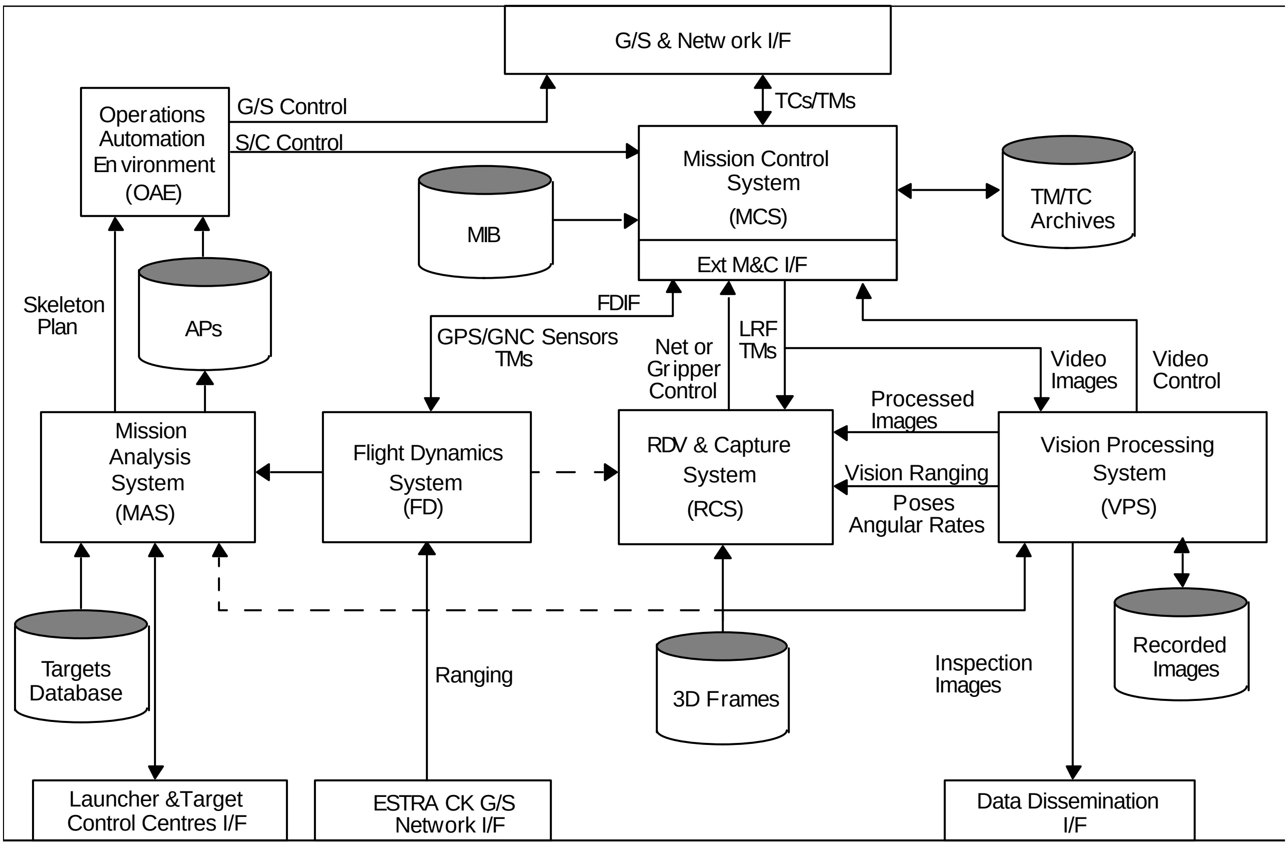


Fig. 4-21: ROGER Mission Control Centre Functional Breakdown

Mission Phase	Time Coverage	Function	Communications Needs	
			Downlink	Uplink
From launch to GTO Injection	~ 19 min	TT&C	20 kbps	2 kbps
GEO transfer	Several days			
Phasing	Max 60 days			
Homing/Closing	Max 3 days	TT&C Video Inspection Net/Gripper control Tether control	Tether/Grip: 0.5 – 2 Mbps (2 Hz mono image – 4 Hz stereo image) Net: 0.5 – 2 Mbps (2 Hz mono image)	Tether/Grip: 1 – 2 kbps Net: < 1 kbps
Inspection	1 day/cycle			
Capture	~ 6 hours			
Graveyard Transfer	12 hours		20 kbps	2 kbps

Tab. 4-4: Mission Phases and Communications Needs

Link Budget Calculations

- The ROGER communication system is constrained by the data rate in downlink chain, the limited RF power available for the on-board transmitter, the spacecraft antenna gain pattern and the size and quality of the transportable ground station.

- Assuming spacecraft antenna gain between 6 and 0 dB depending on attitude:
  - 10 W RF is sufficient for downlinking at 2 Mbps on any ESTRACK ground station.
  - 20 W RF are required for downlinking at 2 Mbps on a 7 m transportable ground station.

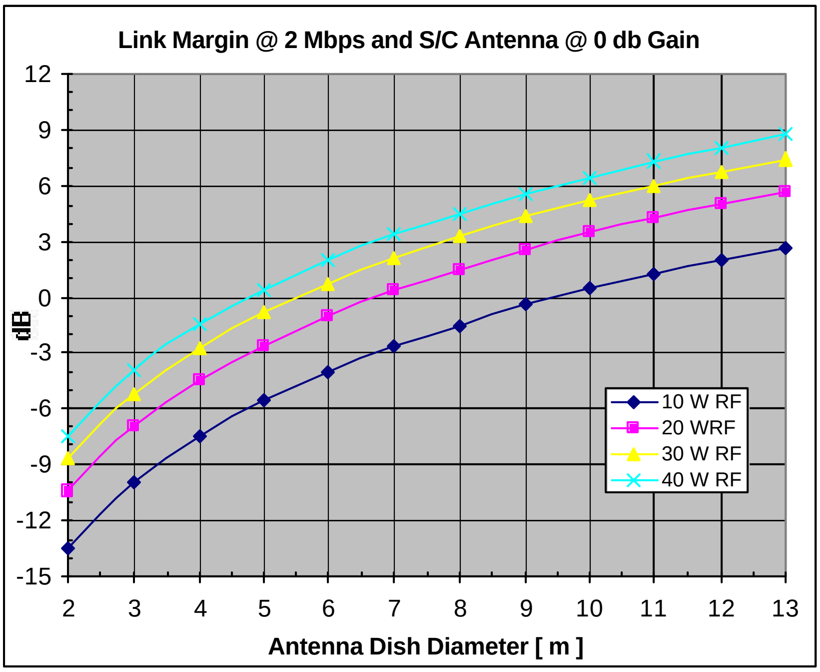


Fig. 4-22: Link Margin

Fig. 4-23: 7.3m Transportable Antenna

Data Rates Requirements

TT&C Data Rates

The TT&C data rates are estimated to be less than 20kbps for platform telemetry downlink and less than 2 kbps for platform telecomand uplink. These data rates will be applicable to all the mission phases.

Target Inspection Data Rates

Video images will be collected during the inspection phase. No requirements are available for the images quality (B&W or colour, image resolution) to determine the image size. We assume thus B&W images of 720x576 pixels digitised on 8 bits giving 33317760 bits/image.

The fly around inspection around the target takes 24 hours, so if we assume that an image is taken on every degree change in this trajectory, an image will be taken every 240 seconds. This gives a downlink rate of 13824 bps without compression if the data is downlinked in real-time. If the fly around trajectory is in the orbit plane, there will be zones where the access to the ground station will not be possible due to ROGER attitude or because the target satellite will eclipse ROGER. Therefore it is proposed to record the inspection images on board and to downlink them when ROGER is in a favourable attitude. As no real-time interactions are required during fly around and because a Laser Range Finder sensor is proposed for the real-time measurement of the distance between ROGER and the target, there are no time constraints imposed for the downlinking of the video data. In case of an in-plane inspection the total drop-outs time covers 1/3 of the inspection period. So, if the on-board stored images are downlinked on top of the images taken in real-time this will result in an increase of the downlink rate by a factor 50 % for a total of 20 kbps.

If the target is tumbling there is probably no need to take images on every degree. Different operational strategies can be applied knowing that a fly around takes 24 hours and that the inspection camera will be controllable during a large part of the inspection period allowing to change the image resolution and compression factors.

Using ESA Rice or JPEG 2000 compression algorithms will allow to reduce at least by a factor 2 the downlink rate.

Finally using colour images would increase the data rate by a factor of 3 which is still acceptable.

In conclusion, the inspection phase is not driving the communications requirements in terms of data rates. It imposes however to use of at least two on-board antennas with a large beamwidth to ensure maximum coverage.

Capture Data Rates

No precise figures are available from the MDR ROGER Video System study [RD6] to date. The draft output from WP4234 performed by DLR [RD7] proposes the following data rates based on image of (512x512 pixels x 8bits) and compression CF ~1:8 assumed giving approximately 250 kbits per image.

For the tether-gripper solution:

- The downlink of 1 mono image at 2 Hz (chaser camera) and/or 2 stereo images at 2 Hz (gripper camera) together with the telemetry from the tether-gripper would require between 0.5 to 1.5 Mbps.
- The downlink of 2 stereo images at 4 Hz only from gripper camera during gripping phase would require 2 Mbps.
- The uplink would require less than 2 kbps for the sending telecommands at 5 Hz maximum for controlling the navigation and orientation of the gripper to the target and for its capture.

For the net-gun solution:

- The downlink of 1 mono image at 2 Hz and the telemetry from the chaser position would require about a data rate of 500 kbps.
- The uplink would require less than 1 kbps for the telecommands controlling the positioning of ROGER relative to the target but this control would in fact be included in the TT&C channel.

These figures should be confirmed however with DLR and MDR. In case stereo images at 4 Hz are indeed required, the S-Band communication system will have to be specified to downlink at the data rate of 2 Mbps.

Nota:
Uplink requirements for capture control impose a data rate of 200kbps if a robot arm has to be controlled with a force/torque and distance sensors control loop closed with a hand-control device by a tele-operator on the ground. For ROGER, it is proposed to use a capture tool in open loop without haptic control. This technique has been successfully used for the ETS-VII robot arm and requires only a data rate of a few kbps in uplink.

Round Trip Time Requirements

The Round Trip Time (RTT) is important for the design of the Mission Control Centre (MCC) components. If the RTT is higher than 500msec, the control in real-time is becoming difficult without the assistance from prediction tools.

The RTT will depend on the location of the MCC. If the MCC is located next to the ground station, the RTT will be between 250 ms and 280 ms depending on the ground station elevation. If the MCC is connected to the ground station through a ground network, then the RTT will be increased by 50 msec using VPN/ATM technology for instance. If the connection is directly relayed from the ground station to the MCC through a IP/VSAT link a delay of 500 ms will occur. This later solution would then impose the use of prediction tools in MCC.

An additional processing delay between 25 to 40 ms will have to be accounted for telecommands transmission between Rendez-vous and Capture System and Mission Control System and for the verification and encoding of the telecommands in the ground station processing chain.

All these delays will be constant and will not severely affect the operations.

Band of Frequency

The TT&C is in S-band (2 GHz) such as to comply with the standards. Considering that there is no scientific payload on-board ROGER and that the data rate of the inspection and capture data will be relatively reduced, this data can be assimilated to TT&C data and downlinked in S-band as well. The maximum downlink data rate achievable today in this band of frequency is about 4 Mbps (convoluted code or 8 Msps). So, the ROGER ground segment should not have difficulty to downlink the expected data (2 Mbps assumed). It should be checked however if affordable solutions exist for the on-board TT&C system.

Downlink chain Modulation

From a link budget performance viewpoint there is no difference in using BPSK or QPSK techniques on the downlink chain. QPSK allows transmission at twice the bit rate of BPSK but requires twice the same energy per bit. The spectrum occupation for QPSK modulation is however half of the one required for BPSK at the price of communication systems that are more complex to develop.

Both techniques are recommended.

Uplink Chain Modulation

The uplink chain is used for the satellite and capture tool commanding. ESA PSS-04-105 and CCSDS 401 B-1 standard recommend for satellite telecommanding in S-Band to use a carrier with phase modulated subcarrier (PSK/PM). With a 16khz subcarrier, a maximum data rate of 4kbps is achievable. For a data rate of 200kbps or above, the PCM/PM/Bi-Phase modulation technique is to be applied. As the data rate in uplink will be below 4kbps, the classical PSK/PM modulation will be used.

5. ROGER D & D Plan

Subsystem and Equipment Qualification Status

Off-The-Shelf Equipment Listing

The following table gives a listing of the off-the-shelf equipment for the ROGER vehicle, but limited to the main equipment of the subsystems.

Subsystem	Component	Remark
Propulsion	1. Bi-Prope3llant tanks 2. 10 N Thrusters 3. 400 N Thruster 4. High Pressure Tank 5. Pressure Regulator 6. Valves, Filters,ect…	
GNC	1. GNC-Computer 2. Star Sensor 3. Coarse Sun Sensor 4. IMU Assembly 5. GPS Receiver 6. GPS Antenna	
Power Supply	1. Battery System 2. Solar Arrays	
Communication	1. S-Band Transmitter 2. S-Band Receiver 3. S-Band Patch Antenna 4. Amplifier, Modem, ect…	
Vision System	1. Stereo Camera 2. Zoom Camera 3. Laser Range Finder	

Tab. 5-1: Off-The-Shelf Equipment

Delta-Development Equipment

Delta development performance is always necessary when the existing components have to be adapted to the special requirements of the planned mission. In the following the main equipment needing such delta development is listed.

Subsystem	Component	Remark
Structure	1. Central Tube 2. Equipment Platforms	
Propulsion	1. UPS Electronic 2. Thruster Clusters 3. Piping	
GNC	1. Software 2. Unit Tester	
Data Handling	1. Software 2. Unit Tester	
Thermal Control	1. Heater-Thermostat 2. MLI Covers	

Tab. 5-2: Listing of Components for Delta-Development

New Development Equipment

The following table is a list of equipment, which is not already existing for the planned project and has to be therefore developed and qualified for the mission.

Subsystem	Component	Remark
Power Supply	1. Harness 2. Solar array Plates	
Data Handling	1. Harness 2. Mission autonomy	
Capture Mechanism (Net capture system)	1. Net release mechanism 2. Net & net closing mechanism 3. Controllable reel and tether	
Capture Mechanism (Tether-Gripper Mechanism)	1. TGM platform 2. TGM gripper 3. TGM ground control	

Tab. 5-3: Listing of New Development Equipment

Phase B/C/D Planning and Cost

Phase B/C/D

The "Definition Phase - Phase B" will be started based on the results of the previous Phase A, eventually a technology study and a Preliminary Requirements review (PRR). During the Phase B the preliminary design is developed and the flight configuration specifications and the ICD's are generated. The preliminary design is supported by alternative investigations and trade analysis for all modules and all subsystems. Intermediate reviews validates the design process. At subsystem/equipment level first breadboard tests and simulations are performed to verify the design analyses and increase confidence in design parameters.
At completion of the definition phase the system requirements are documented in the SRD, flight configuration and subsystem specifications and updated ICD's. The program development is defined in the design, development and AIV plans. The system requirements and program implementation plans are revised and authorised at the System Requirements Review (SRR).

In the Detailed Design and Development Phase C alternative flight configuration and subsystem design concepts are elaborated and validated by detailed design analyses. Critical design parameters and performance data are verified in breadboard tests of the subsystem S/W and H/W. This may include full avionic breadboard , S/W development environment set-ups, GNC/RV dynamic testbed tasks and full model tests.
The design alternatives are reviewed at the PDR against the updated system, flight configuration and subsystem requirements specifications and ICD's. After PDR the detailed design is made for all modules and subsystems. Development models are built and first development tests are made on system level .

During "Manufacturing, Integration and Qualification - Phase D" the qualification units are subject to qualification tests and all S/S will be qualified. Qualification on flight configuration level is supported by tests with the STM, ETM and CTM models.This will be followed by manufacturing of the flight units and subsystems and the assembly , integration and acceptance tests. Assembly integration and acceptance tests of the first flight vehicle (PFM) will lead to the performance of a Final Acceptance Review for the system and begin of the launch campaign.

Time Schedule

The following figure presents the Master Bar Chart of the ROGER Phase C/D.

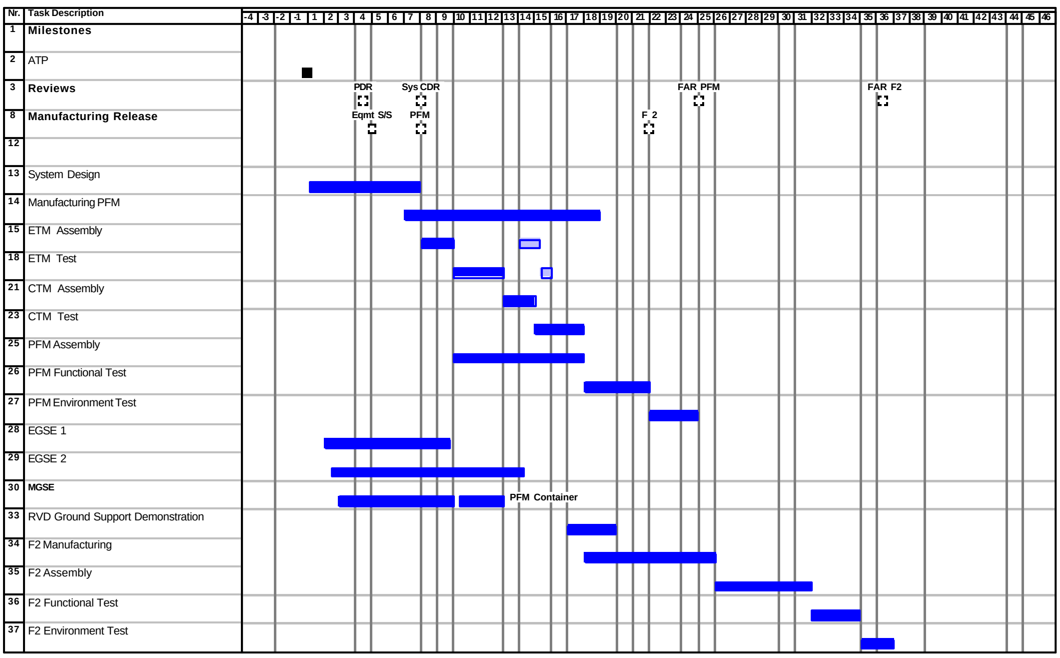


Fig. 5-1: ROGER Master Bar Chart

6. ROGER Demonstrator

Mission Analysis

The reference mission of ROGER demonstrator has two main objectives:

- perform a demonstration of a rendezvous and an inspection of a passive target,
- complete an observation of the debris present in the vicinity of GEO, with the help of a telescope.

The main features are the following:

- Launch on a commercial ARIANE 5 flight as an ASAP payload in GTO. The demonstrator is jettisoned after the commercial mission,
- The demonstration consists of an “inspection” of the ARIANE upper-stage (rendezvous and flyby), and then observation of GEO objects during different orbits,
- The mission is performed by three impulsions that have been sized. The total mission ΔV is less than 10 m/s and can be performed before the first apogee,
- The safety and ground visibility have been briefly analyzed: no constraints are foreseen and all the manoeuvres can be achieved in field of view of the Malindi ground station.

Mission Phases

The mission of the ROGER demonstrator is divided into different phases. The inspection phase is performed first, followed by the observation phase.

Mission operations

The main phases of the ROGER demonstration mission are defined in the context of an Ariane 5 GTO commercial mission. The demonstrator is launched by Ariane 5 on a GTO, as a piggyback (using an ASAP adapter).

The main phases of the active part of the mission are:

- after the injection in GTO, the demonstrator is separated by means of springs,
- a waiting period is implemented in order to reach a relative distance of several hundred meters between the demonstrator and the upper stage,
- the demonstrator performs the first ΔV in order to rendezvous with the upper stage,
- once the relative distance is low enough (about 50 meters), a corrective ΔV is completed in order to start the inspection trajectory,
- after the inspection phase (which lasts about 4 hours), a clearance manoeuvre is implemented to avoid any risk of collision with the upper stage,
- after several orbits (in order to prepare the observation mission), the demonstrator is used to track and observe debris located in the vicinity of GEO ; this part of the mission may last up to 6 months (repeating the measurements while the demonstrator is in the vicinity of GEO),
- at the end of the mission a final ΔV can be performed to clear the altitude of GEO.

Mission Aspects

Orientation of the Orbital Plane

As the ROGER demonstrator platform will be launched as a piggyback payload on an Ariane 5, certain parameters are pre-given and should not be subject to an investigation. Among those parameters are the typical inclinations (5…7 degrees) and perigee altitudes (500…700 km) of Ariane 5 - GTOs. In addition to that, the launch policy of Arianespace will also predefine that the initial position of the GTO apogee will be facing towards the sun with only slight modifications possible. Thus, the initial orientation of the demonstrator orbit will only vary with the chosen launch date of the Ariane 5 launcher.

The main task of the telescope on board the demonstrator spacecraft will be the observation of orbital debris in the geostationary ring region. As small-sized debris objects can only be observed from distances lower than 1000 km, as it will be shown later, an observation of GEO debris objects will only be possible near the GTO apogee. Thus, it is of high importance to consider the (changing) position of the GTO apogee with respect to the possible positions of most GEO objects.

Instrument Aspects

Object Pass Characteristics

Range

Fig. 6-1 is showing the relationship between the detectable diameters and the mean distances of the target objects. At 4000 km distance, only objects larger than 10 cm diameter can offer a signal-to-noise ratio higher than 2.5. All signals of smaller objects in that distance would be too faint. This figure also shows that for a GTO-based sensor only in the area near the GTO apogee relevant GEO objects (unknown or assumed debris objects) can be observed. Thus it would be sufficient to operate the sensor just from 2 hours before the apogee passage to 2 hours after the apogee passage in case only GEO objects were in the focus of interest.

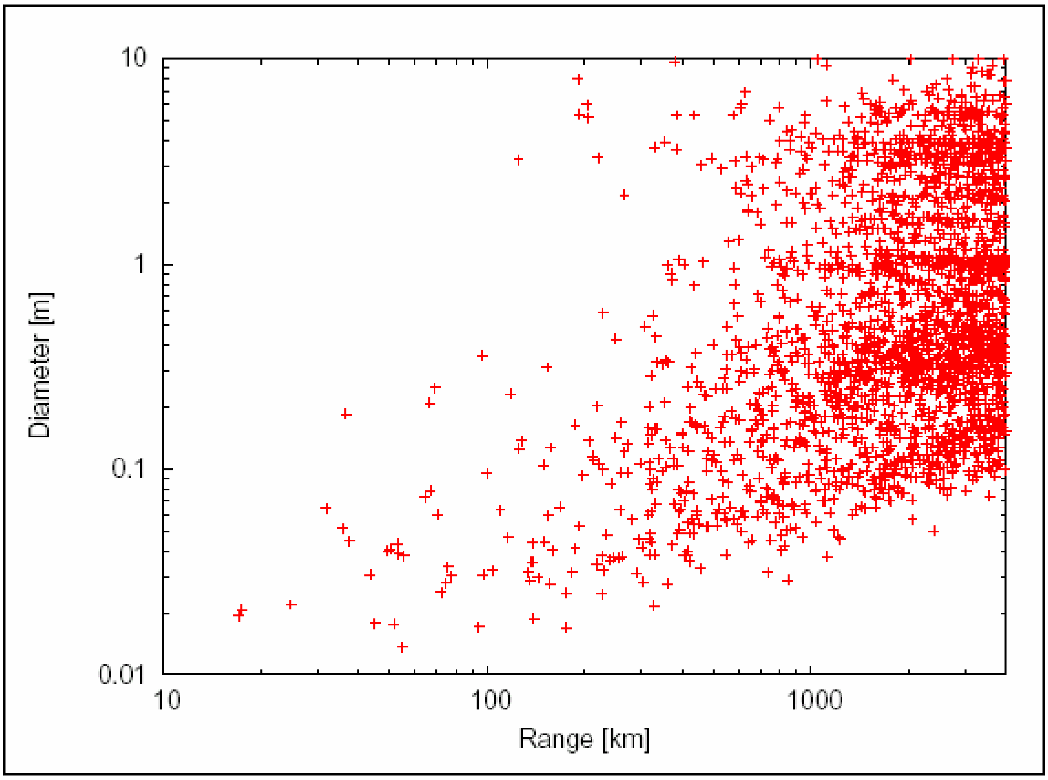


Fig. 6-1: Objects with SNR above 2.5 (15 cm aperture, 15 degree FOV, GTO at 5.2°)

Angular Velocity and Field of View Dwell Time

The mean angular velocity of the target objects relative to the sensor is also a very good indicator of the orbit type of the object. The LEO objects observed from the sensor around the GTO perigee have angular velocities between 0.08 and 3 degrees per second. GEO objects would show angular velocities between 0.02 and 0.3

degrees per second. The lower angular velocities of GEO objects make them more favourable targets with stronger signals thus enabling the sensor to detect smaller objects in GEO than in LEO.

The field of view dwell time is related to the angular velocity of the target objects. It is a driver for the selection of the integration time to be chosen for the optical sensor. The integration time should be short enough to have both beginning and end of a characteristic target object streak on one particular caption. This criterion would be fulfilled if most FOV dwell times were larger than the integration time. On average, the FOV dwell time is at about 150 seconds. If an integration time of 10 s is chosen, the above mentioned criterion would be fulfilled for all GEO objects and for most LEO objects detected by the sensor onboard the ROGER demonstrator spacecraft.

Possible target orbits

The angular velocity has an impact on the detectability of smaller objects. The instrument on board the ROGER demonstrator spacecraft could only detect objects larger than about 10 cm diameter in LEO while it would be able to detect objects down to 1 cm diameter in the geostationary region.

The message of this figure is clear: an observation of non-GEO objects is not desirable. The LEO objects that the sensor could observe would be fairly large and could thus be assumed to be already catalogued. Operating the sensor near the perigee would thus only make sense for calibration and test. The ROGER telescope is very suitable for the observation of objects in the geostationary ring region. The number of detected GTO objects is negligible due to the low encounter probability.

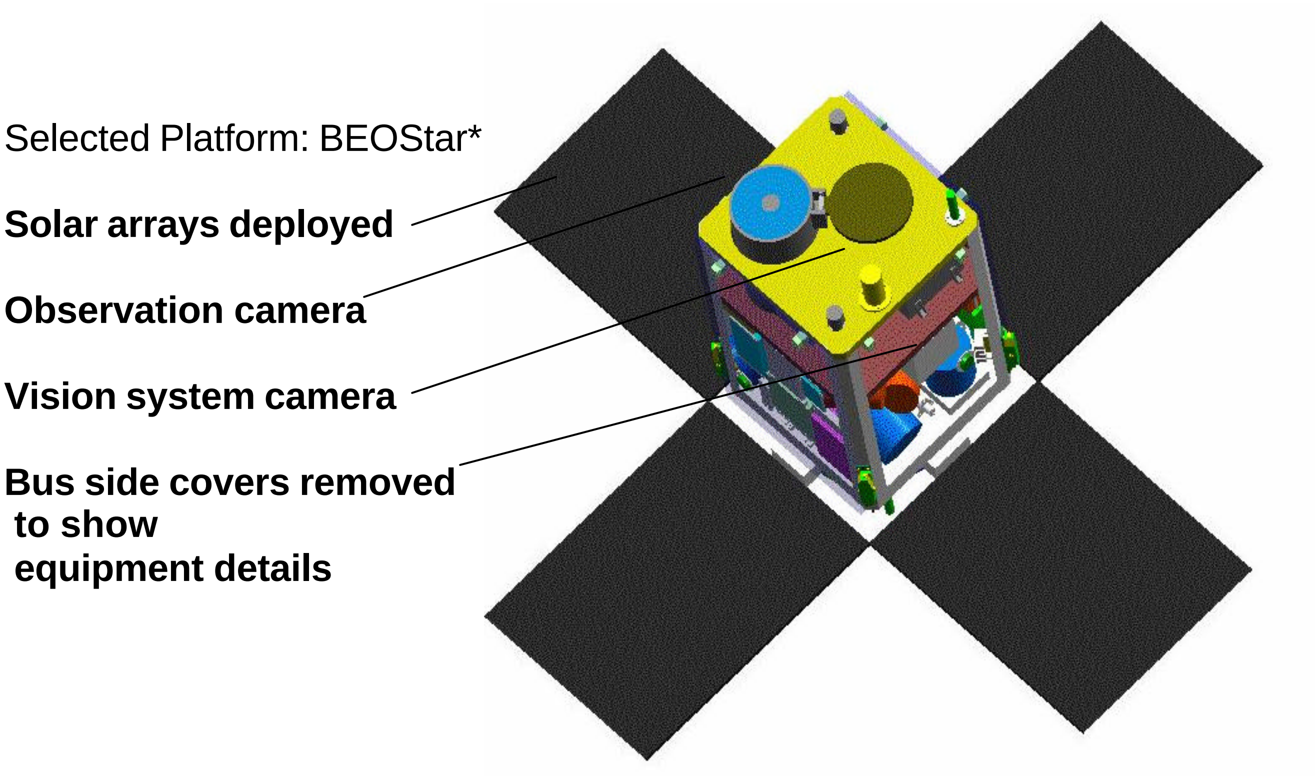


Fig. 6-2: Flight configuration

Upper stage rendezvous and fly-by demonstration phase:

- use vision system with medium resolution and MPEG compression → 500 kbit/s data rate
- use of Malindi ground station with 15 m antenna for complete coverage of event
- link budget shows 3 dB margin for 10-6 BER, 5 W RF S-band transmitter power

- after performance of clearance propulsive manoeuvre, data transmission and control can be performed by use of VSAT station

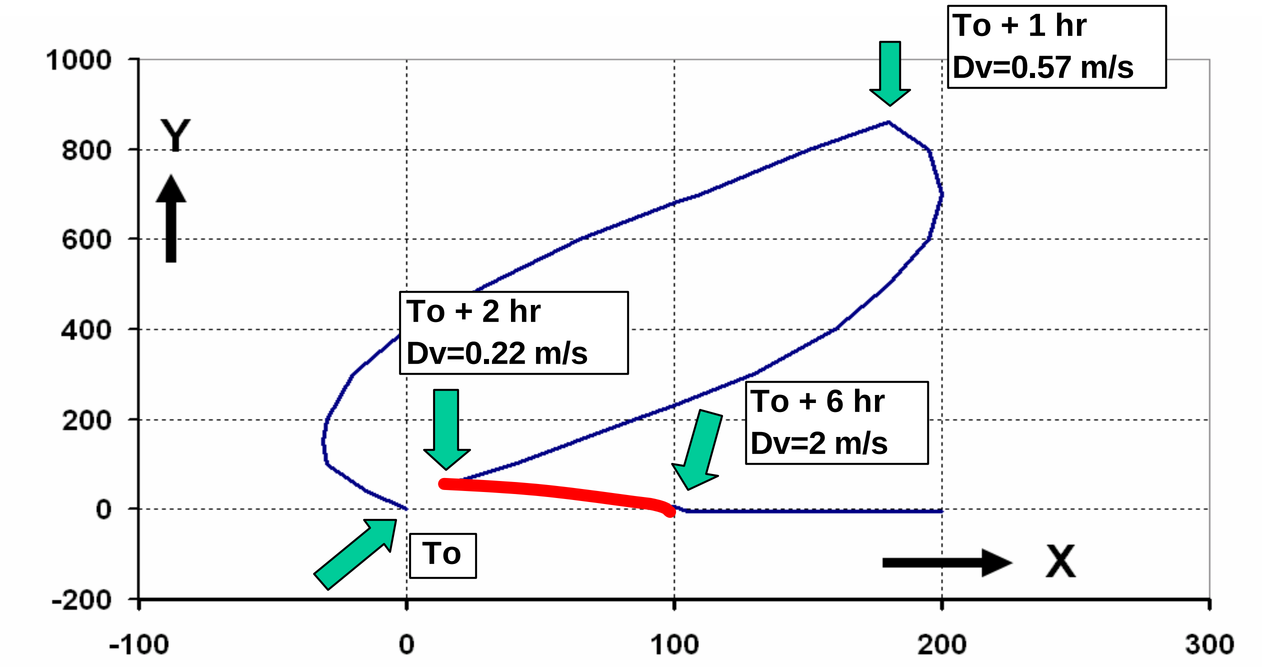


Fig. 6-3: Mission Scenario

Debris detection phase

- 2.75 Mbit on-board storage volume are required for three days (3 x 24 / 10.5 x 400 kbit)

? can easily be accommodated within the platform mass memory

- data volume using data compression and algorithms → 50 kByte per orbit (400 kbit)

? no hard requirement on storage or transmission

- stored volume can be downlinked within a 10 minute period at a rate of 5 kbit/s at 5 W RF power
- data can be received by S-band VSAT ground station (location as required, e. g. mid Europe) with 2 m dish, however steerable antenna provides safer access

? link budget shows 5 dB margin (BER 10-6) for this assumption

ROGER Demonstrator Option

- Objective: True demonstration of ROGER debris and spent satellite removal capabilities by a low-cost mission
- Means:
  - Piggy-back flight into LEO or SSO with Rockot launcher
  - Ejection of 2.5 m dia ring-size target after separation of main passenger
  - Subsequent capture of target with net- and-winch mechanism
  - Observation by camera in real-time
  - Retraction of entangled net and target toward Breeze upper stage
  - de-orbiting of captured debris and Breeze upper stage by de-orbit burn and destructive re-entry

Net Capture of previously separated ring target and real time video transmission to ground station (Ki-runa)

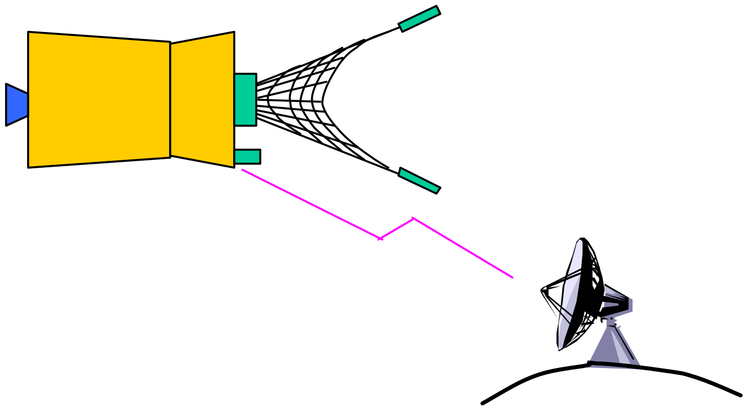


Fig. 6-4: Roger Demonstrator Option Scenario

Required hardware:	
• **Target ring**	**18 kg**
• **Net capture mechanism**	**10 kg**
• **Observation camera**	**1 kg**
• **Modulator and transmitter**	**1 kg**
• **Total mass**	**40 kg**

Tab. 6-1: Demonstrator Mass Budget

7. Commercial Implementation

Cost Analysis Architecture

Throughout the study progress it became more and more evident to analyze beside the technical issues for a future ROGER system also the costs for the development and manufacturing of the spacecraft and the costs and benefits of the utilisation phase.

Therefore an evaluation and cost simulation tool was created to**:**

- provide initial data for a future commercialisation discussion
- define an initial concept for cost / revenue analysis for ROGER
- analyse impact of project & financing responsibilities
- perform a rough cost sensitivity analysis

The analysis was performed in a spread sheet format, in which all relevant input and background data are listed and grouped in different tables and in which the results are shown in compact format

The basic schemata and architecture for the calculation of the cost and revenue data for ROGER has been established such, that all data are grouped into 5 different tables for:

- **General Condition table**, an input table where all external variables for the calculation are summarized
- **Launcher table**, a table in which the relevant cost figures of the different launcher alternatives are listed. These cost figures are stored as specific prices (Launch costs [$] per 1 kg payload mass)
- **Cost table**, in which all costs of the initial ROGER spacecraft as well as for the first additional Follow-on ROGER spacecrafts are calculated.
- **Revenue table**, in which a first estimation of the mission costs and possible revenues are summarized.
- **Result table**, in which the variation analysis input data and the results are summarized.

As a general commitment all cost data are based on year 2002 cost data. Any time dependent variation will be escalated from that basis.

ROGER Costs

In this table the spacecraft and mission related costs are summarized. The project costs are separated into different cost blocks for the spacecraft budgets, the launch costs but also the financing of the utilisation phase including the related administrative budgets such as taxes, insurance fees, etc..

Basically the cost model consists of the different cost items of:

- <u>Development, Qualification and AIV costs for initial an ROGER spacecraft</u>
  For the analysis of the required budgets for the different participants (agencies, industry) in the development, the qualification and the production of the first ROGER spacecraft all costs need to be separated to the specific project phases and participant. Thus the costs for the
  From previous designs of spacecrafts which are similar to ROGER, certain conditions for the ROGER scenario and from historical data available in the Astrium internal databases data for the costs for the different subsystems for the ROGER spacecraft have been collected and used in this initial calculation. In order to separate the costs for the different project phases, the average distribution of costs has been calculated (on the basis of data for equivalent developments derived from the Astrium databases). With this knowledge the entire development, qualification and MAIV costs could be calculated. These cost figures are based on the costs for the year 2002. The real costs are then adapted with the cost escalation rates, the project start and project duration. The data for times and the escalation rates are catched from the <u>GENERAL CONDITIONS</u> table.

ROGER 1				
Spacecraft		Development	Qualification	MAIV
	System	7.350.000,00 €	2.290.000,00 €	6.700.000,00 €
	Structure	1.220.000,00 €	380.000,00 €	1.110.000,00 €
	GNC	8.300.000,00 €	2.600.000,00 €	7.600.000,00 €
	Power	2.070.000,00 €	640.000,00 €	1.890.000,00 €
	Thermal	900.000,00 €	280.000,00 €	820.000,00 €
	Propulsion	3.960.000,00 €	1.230.000,00 €	3.610.000,00 €
	Communication	630.000,00 €	200.000,00 €	570.000,00 €
	Sensor	8.100.000,00 €	2.520.000,00 €	7.380.000,00 €
	Capture Devices	6.750.000,00 €	2.100.000,00 €	6.150.000,00 €
	Ground System	2.340.000,00 €	730.000,00 €	2.130.000,00 €
	Total (Now)	**41.620.000,00 €**	**12.970.000,00 €**	**37.960.000,00 €**
	Total (Escallated)	49.696.456,58 €	15.486.858,29 €	45.326.225,18 €
	Grand Total			**92.550.000,00 €**
	Grand Total, Escallated			**110.509.540,04 €**
	Price per Capture Device			307.500,00 €

Tab. 7-1: System costs for first ROGER spacecraft

- Upgrade development, qualification and rebuild of follow-on ROGER
  The initial ROGER spacecraft will be able to carry max 20 satellites into the graveyard orbit (depending on the selected capture equipment and configuration). After that period additional ROGER spacecrafts will required to extend the "Cleaning" capability in GEO. For this the re-build of a "Follow-on" ROGER is calculated considering certain upgrade developments for the spacecraft configuration. The costs for these upgrades have been judged on the basis of complexity of subsystem and correlated to the "First" ROGER costs by a learning curve effect. The cost data are as the first ROGER data escalated to the expected delta development, launch and utilisation period.

Follow-on ROGER				
Spacecraft		Re-development	Delta-Qualification	Materials, AIT
	System	500.000,00 €	200.000,00 €	1.410.000,00 €
	Structure	200.000,00 €	90.000,00 €	670.000,00 €
	AOCS	600.000,00 €	370.000,00 €	3.500.000,00 €
	Power	200.000,00 €	110.000,00 €	1.140.000,00 €
	Thermal	240.000,00 €	90.000,00 €	670.000,00 €
	Propulsion	440.000,00 €	150.000,00 €	4.020.000,00 €
	Communication	120.000,00 €	50.000,00 €	340.000,00 €
	Sensors	880.000,00 €	540.000,00 €	5.040.000,00 €
	Capture Devices	600.000,00 €	300.000,00 €	6.700.000,00 €
	Ground System	100.000,00 €	20.000,00 €	70.000,00 €
	Total (Now)	**3.880.000,00 €**	**1.920.000,00 €**	**23.560.000,00 €**
	Total (Escallated)	5.370.827,42 €	2.657.729,03 €	32.612.549,99 €
	Grand Total			**29.360.000,00 €**
	Grand Total, Escallated			**40.641.106,44 €**

Tab. 7-2: System costs for additional "Follow-on" ROGER spacecrafts

ROGER Revenues

Beside the costs a ROGER spacecraft will create, this spacecraft will also generate revenues with the inspection and the graveyard missions. All in-orbit operations of ROGER will in the end be paid by the customers of that special service.

To analyze the minimum costs of such missions in a first attempt all known costs for inspection missions and for graveyard missions have been summed up and calculated with judging factors for inconsistencies and variations of conditions.

For the inspection missions the cost share for the assumed inspection mission period for the ground station (transport, renting fees, personal costs), a share for non-operative periods and for consumables based on the assumed annual number of inspection missions has been summed. Inaccurancies in the data and inconsistencies are covered by a 30% miscellaneous overhead. Beside such technically and operationally based cost elements also administrative costs are considered, such as insurance costs, refinancing budgets, taxes, as well as profit, etc. In total the costs for a typical inspection mission will as a minimum cost about 4.8 M€. per inspection mission

For the graveyard missions an identical approach for cost evaluation has been performed with the adoptions in additional costs for expendables (e.g. net), different mission duration, different insurance rates for changed technical and administrative risks. All these data lead to minimum cost for a graveyard mission in the magnitude of about 10.7 M€.

Minimum Mission Costs			
	Graveyarding		**Inspection**
Net	307.500,00 €		0,00 €
Propulsion	222.333,33 €		222.333,33 €
Launch cost part	3.675.000,00 €		2.450.000,00 €
Personal costs	80.000,00 €		13.333,33 €
Ops-Time Costs	12.083,33 €		7.500,00 €
Transport	10.000,00 €		0,00 €
Miscallanieous	1.292.075,00 €		0,00 €
Risk	558.690,83 €		268.566,67 €
Insurance	125.009,36 €		50.009,36 €
Refinancing	2.124.967,08 €		1.018.648,41 €
Profit	1.000.000,00 €		100.000,00 €
Tax	1.261.148,84 €		619.558,67 €
Total (minimum costs)	10.668.807,78 €		4.749.949,77 €

Tab. 7-3: Assumption for minimum costs for ROGER Missions

On the other side the revenues for graveyard missions will be limited by the possible benefits a satellite operator can gain in using the services of a ROGER company.

For the graveyard missions assuming a remaining set of 30 operational transponders (as average) at the end of nominal life for a satellite and by using the residual propellant a prolongation of about 6 months of lifetime a financial benefit for the satellite operator of about 25 - 30 M$ can be expected. A part of this benefit might be used to "rent" the service to graveyard the satellite from a future ROGER company.

For the inspection missions the customer group will include more insurance companies instead of satellite operators but also satellite manufacturers. The benefits for such inspections are located for the insurances in the saving of large "lost" insurance budgets, for the satellite operator in knowing better the status of an inspected satellite (and better judgements of the remaining capabilities) and for the satellite manufacturer in a better understanding of the degradation of satellites and alternative design choices.

A realistic judgement of the upper limit of inspection mission revenues is currently not possible, since the benefits for the customers can not be evaluated.

The business mode in which a possible future ROGER company will work will have a large influence on the revenue model. A long discussed customer model is based on an a partnership between the satellite operator and the ROGER company and assumes, that a customer may approach the Roger company with the problem that his satellite is getting close to EOL. The satellite operator can only estimate the fuel remaining to within approximately 6 months. So to be sure, the satellite would have to re-orbited little more than 6 months before EOL. On the other side the operator would like to continue operations uninterrupted until run out of propellant and would like to avail the ROGER services to re-orbit afterwards. In this case, there might be a way to negotiate a revenue sharing agreement which is cost effective for the operator, and where, if the satellite continues to operate longer than nominally predicted, there would be a price adoption.

Other customers may have operated their satellites as long as they have run out of propellant when he approaches to the ROGER company for support to re-orbit his s/c. In this case a straight mass based re-orbiting charge would be more appropriate.

	ROGER 1		**Follow-on ROGER**
	M€		**M€**
Agency Costs	186,9		7,6
Industry Costs	27,6		158,7
Industry Refinancing	9,3		53,7
Insurance	11,7		13,6
Total Program Costs	**235,6**		**233,5**
Revenue	329,2		381,6
Earnings	93,5		148,1
Tax Amount	14,0		22,2
Total Profit (after tax)	79,5		125,8
Annual Profit Rate (off tax)	6,0%		9,0%

Tab. 7-4: Evaluation Results

8. Recommendations & Further Steps

- **Execution of a Demonstrator Mission to verify the function of the net capture mechanism, communications and operations**

- To convince potential customers a low cost piggyback demo mission is proposed to verify the critical operational technologies and procedures for a net capture mechanism

- This demonstration mission shall be representative using a large scale structure to be captured

- The mission suggested can be performed within two years

- The overall mission cost (ROM) 2.0 M€ includes D & D, manufacturing ,launch and mission operation cost

- **Performance of a detailed market analysis to verify the commercial concept**

- **Initiation of a Phase-B Study inclusive a Business Plan**

- **Establishment of an Industrial and Agencies Working Group to promote commercial concept (For Europe ESA and EU shall give guidance for the creation of a legal organisation)**

- **Identification of capital sources to establish a commercial company structure**