DEOS - THE IN-FLIGHT TECHNOLOGY DEMONSTRATION OF GERMAN'S ROBOTICS APPROACH TO DISPOSE MALFUNCTIONED SATELLITES

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ABSTRACT

There are many concepts how to serve and lift malfunctioning satellites from their operational orbit to avoid large scale damage caused by uncontrollable satellites. For many years Germany has been developing robotic techniques especially to handle its spacecrafts to the very end of life – just until their disposal. The German approach is based on berthing techniques using a manipulator system accommodated on a servicing satellite (Servicer) operated semi-autonomously and from Earth.

1. INTRODUCTION

The number of satellites orbiting around the Earth is increasing rapidly. Nowadays hundreds of satellites used for navigation, television-broadcasting or earth observation purposes populate the Earth orbits. Many of them will reach the end of their lifetime in near future. The Inter-Agency Space Debris Coordination Committee (IADC) requires self-removal [1]; Satellites on/near the geostationary orbit have to lift themselves up to a higher altitude, the so-called graveyard orbit. Satellites on low Earth orbits shall de-orbit to a lower altitude where atmospheric drag would cause it to re-entry within a defined timeframe (max. 25 years).

Although satellites should by definition be able to remove themselves from their orbits, but many don't because of a malfunction or lack of fuel. For maintenance, repair or refuelling satellites must be captured in a safe and secure way avoiding any damage in the process. The German approach to serve, secure and de-orbit uncontrollable satellites is based on a robotic agent (see Fig. 1), a sufficient servicing satellite equipped with at least one manipulator.

Beside the robotic technologies and tools there are also other aspects to be taken into account. Operational procedures, data communications or approach techniques play a vital role on the way to capture an uncontrollable satellite in a safe and secure manner. These aspects are of major interest within the scope of **DEOS (Deutsche Orbitale Servicing Mission)**, Germany's on-orbit servicing satellite concept, to find and evaluate procedures and techniques for rendezvous, capture and de-orbiting of an uncontrollable satellite from its operational orbit.

2. DEOS – A ROBOTIC SERVICING MISSION

German institutes and companies research the field of maintenance and repair technology for space systems and On-Orbit-Servicing (OOS) by the means of robotics technology for many years. Step by step light weight robotics joints, concepts for their intuitive remote control from ground (tele-presence) as well as the maintenance capability of space robotics tools and general technologies were explored, improved and mostly space qualified, now ready for demonstration in DEOS, a comprehensive, surrogate technology verification of an OOS application.

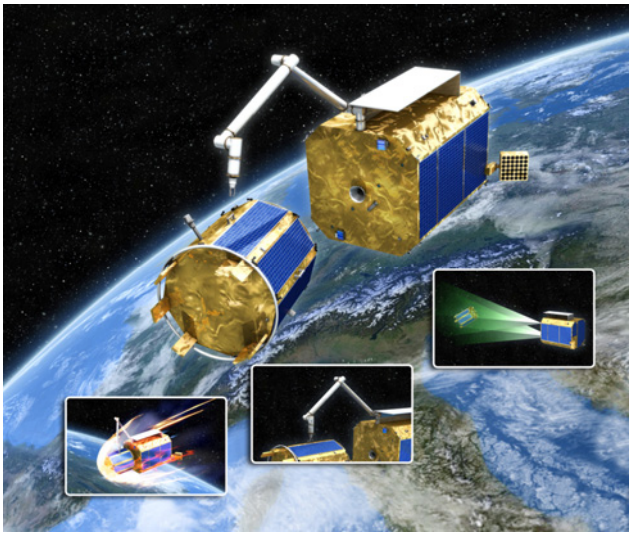

Figure 1. DEOS – Satellite On-Orbit-Servicing

2.1. Mission Objectives

Taking all programmatic aspect on On-Orbit-Servicing (OOS) into consideration DEOS shall validate and demonstrate the technical feasibility of advanced maintenance and servicing of a spacecraft. This means features like (tele-) manipulation, on-orbit reconfiguration and perhaps refuelling concepts need to be demonstrated.

This intent led straight to the formulation of the DEOS mission statement which defines

- Capture a tumbling, non-cooperative satellite using a manipulator mounted on a free flying service-satellite,
- Demonstrate a servicing application and
- De-orbit the captured satellite within a pre-defined re-entry corridor.

Non-cooperative used in the sense of not supporting the rendezvous and capture process with any signals or features.

The overall space segment of DEOS consists of two satellites which will perform and demonstrate all aspects and maneuvers needed to cover future satellite servicing tasks. One spacecraft represents a passive, non-cooperative and tumbling target satellite (Client) to be captured by the second one, the active free flying servicing satellite (Servicer). The core spacecraft maneuvers to be performed are far rendezvous, close approach, inspection fly around, formation flight, capture, stabilization and calibration of the spacecraft compound, compound flight maneuver and controlled de-orbiting of the compound, the rigidly coupled satellite configuration.

Herein, robotics is highly involved in capture, stabilization, orbit maneuvers and even the de-orbiting. The main objective of the capture experiment is to investigate different control strategies and AOCS (Attitude and Orbit Control System) control modes, as well as to determine suitable maneuvers for soft docking and the subsequent stabilization of the coupled spacecraft.

Depending on the task and the technology readiness Servicer operations will be planned and initiated from ground but shall be performed autonomously when ever possible. During passive ground control spacecraft operations are only monitored by the human operator on ground (supervised-autonomous control mode). An active ground control mode enables tele-operation services which let the human operator immediately command and control the remote service-spacecraft instead of only monitoring it.

2.2. Mission Description

Both spacecraft are designed for an injection into an initial low Earth near polar orbit of 87° about 550 km above the Earth. The near polar inclination offers variable illumination conditions over the life time for the planned complex demonstration program. The initial orbit altitude will be decreased stepwise during the one year orbital lifetime in order to increase the operational complexity caused by reduced contact time to the communication network.

The Mission is divided into four standard operational phases:

- Launch and Early Orbit Phase (LEOP),
- Commissioning Phase,
- Operations Phase and
- De-Orbiting Phase.

A stack configuration is chosen for launch. The two satellites are rigidly connected to each other to inject both together into the initial orbit on one launcher. After the launch and early orbit phase (LEOP) the commissioning of both spacecraft will also be conducted in the stacked configuration. LEOP will include typical activities like the separation from the launcher, the activation and establishment of the TM/TC links and the validation of basic system checks.

At the end of the commissioning phase both satellites will have completed the most important calibration activities. Both satellites will be in a stable operational state and ready for missions operations. Sequences of the commissioning that are not possible or only possible with hard constraints in the stacked configuration will be postponed to a later delta-commissioning phase, either during the berthed configuration after stack separation, the initial departure as part of the rendezvous phase or in the far formation flight (see Fig. 2).

At the beginning of the mission operational phase (see 2.3) both spacecraft will remain in the launch stack configuration for a certain period of time. Within this configuration first OOS activities (see 2.4) will be executed. Attitude and orbit control of the stacked configuration is done by the Servicer.

After separation of the launch stack configuration both spacecraft will finish the delta-commissioning and start to perform maneuver and experiments to demonstrate the various mission objectives. Once separated, the spacecraft can not go back to the initial launch configuration because the stack separation mechanism is not reversible. A rigid reconnection can only be achieved via the unified berthing and docking port mechanism (UBDM, see 4.1.4) which features a different state, a rigidly coupled configuration.

In general the complexity of the demonstration program is going to be stepwise increased over the operational mission phase. One major of interest is the demonstration and verification of methods to capture a non-cooperative, tumbling satellite using a manipulator, the so called berthing approach. During berthing all capture tasks are controlled by the manipulator, in contrast to docking where the interconnection of the satellites will be controlled by the reaction control system of the Servicer.

According to the mission objectives the berthing approach implies spacecraft operations and maneuvers

(see 2.3) to be fulfilled including far formation flight, rendezvous maneuvers, fly-around and inspection flight, up to the capturing of the Client with the manipulator under different environmental and operational conditions as well as different attitude states of the Client.
At the end of one year mission operations time both spacecraft shall have decreased the orbit altitude stepwise to 450 km. From here de-orbiting and re-entry within a predefined re-entry corridor will be initiated by the Client. At the beginning of the re-entry trajectory the spacecraft shall be rigidly coupled using the manipulator arm as mechanical fixture. During re-entry the spacecraft shall disintegrate into smaller peaces which then will burn up in the Earth atmosphere.

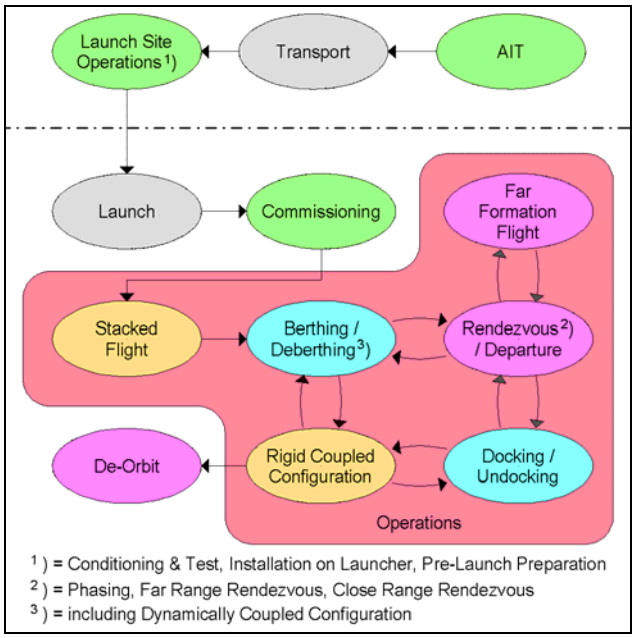

Figure 2. Operational phases and transitions

2.3. Mission Operational Phase

The in-orbit operational phase of the mission is divided into several sub-phases as shown in Fig. 2. During the operational phase both spacecraft will perform a comprehensive demonstration and verification program covering all typical situations of a satellite servicing mission (see Fig. 3).
The demonstration and verification program starts with the activation of the separation mechanism with the Client staying grappled by the manipulator of the Servicer. In this berthed configuration the close range sensors can be tested and calibrated by moving the Client around in the maneuvering range of the manipulator arm. Furthermore, initial experiments concerning the dynamically (undammed by manipulator) and fixed coupled configuration can be executed without the need for any rendezvous maneuver before.

After this sequence the two spacecraft will be de-berthed and brought to a safe point out of reach of the manipulator arm. Here, the Client is still in the range of the rendezvous sensors but collisions between the satellites can not occur. From the safe point the close range rendezvous and berthing shall be demonstrated. After this the Servicer shall move away from the Client up to the far formation flight distance.
In the far formation flight, Servicer and Client are flying in a constant distance from each other within pre-defined tolerances using absolute navigation sensors. The distance between both spacecraft is farther than 2 km. Implemented safety features avoid potential collisions even without ground control over a couple of days. During far formation flight the dynamical behaviour of each individual spacecraft shall be determined and the spinning and tumbling motions of the Client can be tested.
The far formation flight is the starting point for the rendezvous (phasing) operation. Starting from the far formation flight state the Servicer has to find the Client and navigate towards its position. At the end of the flight approach the Servicer has to take a close, safe parking or mating position. The distance between Client and Servicer shall be within the operating range of the manipulator as shown in Fig. 7. The mating position for capturing is maintained using the relative navigation sensors. The contact point for grappling has to be in the field of view of the manipulator cameras and will be tracked either by the operator on ground during tele-operation or autonomously by means of on-board image processing.

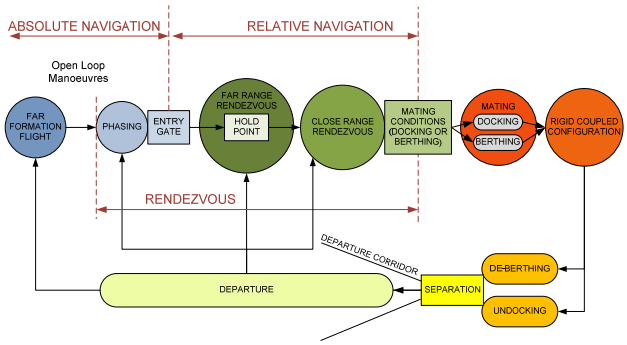

Figure 3. Linear transition diagram of far formation flight, rendezvous, berthing/docking and departure

During berthing the Client shall be grappled by the manipulator and latched onto the unified berthing and docking port mechanism (UBDM). The manipulator will also be applied to capture the Client, to stabilize the grappled compound and to move the Client from the capture position to the UBDM port. Once both spacecraft are rigidly coupled the manipulator can be released from the Client in order to be free for other maintenance tasks or it will be folded away and remained in its parking position.
Berthing shall be performed on the so-called supervised

autonomous mode as well as steered via tele-operation by the operator on ground. Other steering maneuvers are also possible, e.g. to move the grappled Client into a position suitable for flight maneuvers in the rigidly coupled configuration.

De-berthing is the separation of the Client from the UBDM port and moving it with the manipulator to a releasing position. From here the Servicer can depart from the Client to the safe inspection point.

Docking is based on the reaction control system and the docking camera images of the Servicer. Here, the Client is not longer a non-cooperative target. Instead it actively supports the docking process. The Servicer slowly approaches along the docking axis from the mating position towards the Client. Marker LEDs on the Client have to be in the field of view of the docking camera in order to determine the relative position and attitude between Servicer and Client. Docking can be performed in two ways: on-board-autonomously or via ground control. The interconnection of the two satellites will be carried out by inserting the docking interface of the Client into the UBDM port on Servicer side.

Based on the image processing the Client's docking interface will be kept well aligned with the axis of the Servicer's docking port using the Servicer's reaction control system. In case of supervised-autonomous docking the relative navigation is based on the on-board processing of the docking camera images. If the docking is performed via tele-operation the relative position and attitude of the Client are provided via ground.

For undocking the Client's docking interface will be entirely released from the docking port of the Servicer. Both spacecraft still drift apart with their AOC actuators deactivated. The movement may be monitored by means of the docking camera images. The transition to the departure phase is smooth, since the movement is not stopped at the mating position.

Departure starts after separation when the relative navigation sensors are activated at the mating position. A maneuver is initiated which moves the Servicer out of the close range of the Client. During this phase the Servicer monitors autonomously the trajectory making sure that it stays within the predefined departure corridor. In case of a failure independent collision avoidance algorithms will come on-line to perform a safe separation maneuver.

The departure may consist of a number of orbit maneuvers. Those maneuvers have to take into account that there has to be ground contact in order to monitor the switch over from mid range to far range cameras and from relative to absolute navigation within the range of the rendezvous entry gate. The departure phase ends when reaching the desired destination orbit.

2.4. On-Orbit Servicing Task

The manipulator will be used to perform exemplary on-orbit servicing tasks.

An observation camera brought by the Servicer shall be mounted and activated on the Client. This servicing task extends the functionality of the Client. Launched as a "blind" spacecraft the Client will then be able to observe the Servicers operations during its demonstration program. The camera will be installed and activated before the first separation of both spacecraft after launch and commissioning.

Further activities focus on experiments investigating the dynamic behavior and parameters (mass, centre of mass, moments of inertia) of the various flight configurations. At the moment two experiments are currently being analyzed: perform attitude maneuvers by using the actuators and sensors of the AOCS system and using manipulator motions in combination with the sensors of the AOCS system to control attitude. The knowledge about the dynamic behavior is essential for all orbit and flight maneuvers in the coupled configuration.

Within the scope of the comprehensive rendezvous and capture demonstration program, the demonstration of controlled de-orbiting (up to the re-entry) of the spacecraft compound, performed and controlled by the Client, is a primary goal of the DEOS mission. Servicer and Client are trading their roles for these maneuvers in order to simulate a realistic re-entry situation. The center of mass of the compound will be located outside of the spacecraft which performs and controls the de-orbiting operation.

Finally, a refueling experiment, i.e. transfer fuel between the two spacecraft, is also under discussion but a decision is yet not made.

3. GROUND CONTROL CONCEPT

The core element of the ground segment is the Mission Control Centre (MCC). Data signals to and from the spacecraft are transmitted and received through the antennas of the primary ground station facility which is directly connected to the MCC. All spacecraft operations must be integrated into the multi-mission commanding chain of the MCC. Thus, a mission specific payload control system as part of the MCC provides all necessary command interfaces for the human operator to tele-operate the servicing satellite and /or monitor the servicing operations.

3.1. Tele-Operation Concept

Germany has investigated the feasibility and limits of technologies and tele-operation concepts for on-orbit servicing within several space missions like ROTEX, GETEX or ROKVISS [4, 5]. As a result it was demonstrated that during (direct) radio link contact a remote robotic manipulator can be commanded by a human operator via improved supervisory control techniques as realized in the Man-Machine-Interface (MMI) of DLR's MARCO telerobotic ground station [4]. Pre-defined robotic tasks can be performed autonomously by sending a path or trajectory to the on-

board system. Even high-fidelity force feedback control is applicable using a direct radio link [3, 6].

While the Client satellite of DEOS will be operated as a standard spacecraft the servicing satellite is operated in different modes. Core satellite functions as collision avoidance or attitude control are board-autonomously performed under responsibility of the on-board data handling system. In spite of higher level servicing operations like rendezvous, berthing or docking maneuvers the human operator is either only monitoring autonomous operations or tele-operates the spacecraft, even directly perform a specific servicing operation like the capture task.

In order to keep the round-trip communication time during tele-operation, especially for mission critical maneuvers or operations, as low as possible the operator on ground shall have access to the space segment using a direct high-performance S-band radio link. An S-band radio link enables closed loop control of the spacecraft. In case of unpredicted system behavior or failures the operator is able to come into action just in time. But as outlined in Fig. 4Figure the S-band link for operations will be available only for a few minutes depending on the path and the ground track abilities. Thus, an operator on ground is limited in time to serve, to monitor and to command the system. Complex servicing operations need to be prepared, subdivided and then performed involving more than just one ground station. But using such a ground station network causes other difficulties and technical drawbacks.

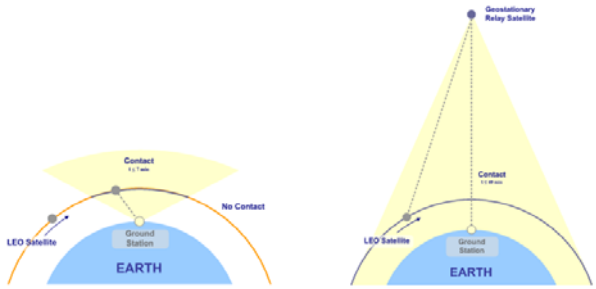

Figure 4. Communication approach: (left) access via S-Band link (right) access via GEO-Relay Satellite

Thus, additional communication via geostationary relay satellites shall be utilized whenever it is considered beneficial for the smooth and safe execution of the DEOS mission, especially to increase the time for operational access.

3.2. Communication Architecture

The communication architecture defines S-band as the primary radio link for both spacecraft. In addition, the servicing satellite provides an inter-satellite Ka-Band system to transmit and receive data to and from the MCC via a relay satellite. The complete chain of the communications architecture together with its major components is shown in Fig. 5. The complete system consists of the Servicer satellite with its inter-satellite Ka-Band system, the GEO Relay Satellite (i.e. ARTEMIS) and a Ka-Band ground station.

The communication concept for telemetry and telecommand (TM/TC) is the same for all three components. Telemetry will be down-linked at the rate of 4 Mbps (including 3,5 Mbit/s video data), whereas different types of packets are merged in that link (HK, images). Telecommands will be up-linked at a rate of 256 kbps, while different sort of packets are merged in that link (i.e. Satellite commands, Robotics commands, Uplink messages).

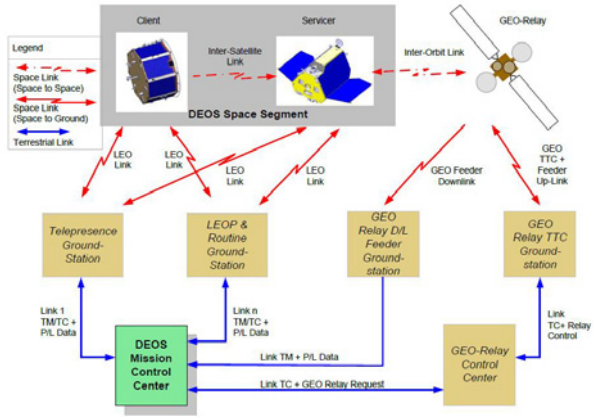

Figure 5. Communication Architecture

4. SPACE SEGMENT

The space segment comprises two satellites, one resembles a non-cooperative tumbling satellite (a space probe circling Earth on an unstable trajectory) to be caught by the active service satellite (Servicer). For this goal, the Servicer features a so-called “manipulator”, a robotic device mounted on its top. A brief description of the spacecraft and their payloads as shown in Fig. 6 is given in the following subsections.

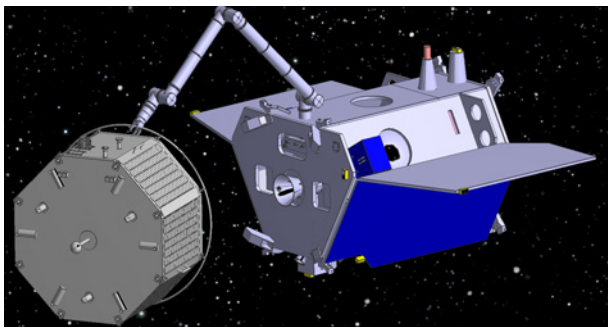

Figure 6. DEOS Servicer and Client Spacecraft

4.1. Servicing Satellite (Servicer) Spacecraft

The Servicer will be equipped in the way that it is able to act as a servicing spacecraft and fulfill all basic tasks necessary for OOS.

4.1.1. Servicer Bus Concept

The core infrastructure of a spacecraft is the satellite platform, typically a mission specific design to provide best locations for the instruments and other payloads. The overall concept of the DEOS Servicer spacecraft is shown in Fig. 6. The main body of the Servicer spacecraft is designed as a cuboid with four circumferential areas. Three sides as well as the rear side are partially covered with body mounted solar array cells. The chamfered edges as well as parts of the cover plates are used for thermal control.

The resting place for the manipulator arm in a thermal protective cover as well as the Ka-Band antenna is accommodated on one of the four circumferential plates. The Ka-Band antenna and its associated 2-DoF pointing mechanism is folded and attached to the spacecraft outer structure for launch reasons. During the demonstration program the antenna has to be unfolded and activated to track and point for the relay satellite. The S-Band antennas, one for the ground link and a second one to receive the Client communication channel, are accommodated on the Servicer surface.

One major point of interest is the control strategy of the Servicer during capturing. In the first case, the AOCS reacts to limit or eliminate any spacecraft motion (therefore the spacecraft can be kept stationary in operational space), while in the second case the spacecraft is allowed to move in reaction to the robot movements. While the first case is easier to tele-operate and may be necessary to fulfill spacecraft motion constraints (e.g. attitude motion may be limited for communication purposes), the second case is more interesting for reducing fuel consumption for spacecraft control and may be safer, since jerky motions which may arise from firing the thrusters will be avoided.

4.1.2. DLR's Light Weight Manipulator

The robotic arm (manipulator) bases on DLR's light weight manipulator design as space qualified within the ROKVISS mission [3]. Equipped with an appropriate end effector (see 4.1.3), the manipulator is responsible to serve and handle the Client who has to be captured, stabilized and attached to the UBDM port.

Thus, the arm has to have a sufficient minimum length to allow all tasks to be performed with the Client in any position and spinning or tumbling state. During launch the arm is folded and attached to the Servicer spacecraft outer structure.

The manipulator arm consists of 7 modular, torque controllable joint elements as developed for ROKVISS with slight modifications concerning the implementation of a parking break. Such a break is necessary to keep a fixed configuration of the two spacecraft when physically connected via the manipulator arm. This 7-joint arrangement provides kinetic redundancies in order to avoid joint singularities during the capturing or servicing process. The operating envelope in terms of possible gripper orientations of the manipulator arm with its defined allocation on the Servicer spacecraft is depicted in Fig. 7.

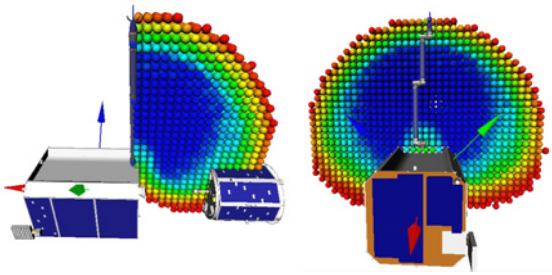

Figure 7. Operating range of the manipulator arm.

4.1.3. Grappling Mechanism (Gripper)

The manipulator arm is equipped with a 3-finger grappling mechanism that allows to capture a moving structural part of the Client satellite and to handle objects during the manipulation/servicing experiments. The layout and main elements of the mechanism are outlined in Fig. 8 (left). The motor torque is applied via a spindle-gear to a toggle-lever mechanism which allows a very fast closing speed at the beginning and a very high grasp force at the end of the closing motion.

The gripper is equipped with an illumination system and a camera with a field-of-view angle of about 60° to allow any object to be visible until it is within the gripper yaws. The camera and gripper harness will be routed to the interface control unit through the hollow axles of the manipulator joint elements.

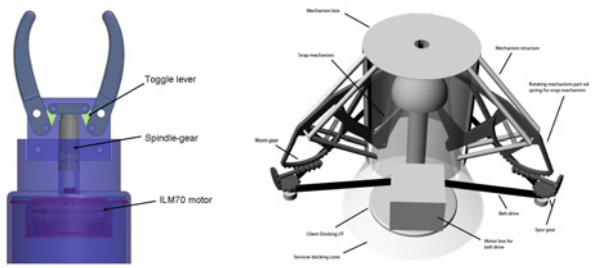

Figure 8. (a) Gripper mechanism (left). (b) Unified Berthing and Docking adapter (right)

4.1.4. Unified Berthing and Docking Adapter (UBDM)

Latching is the final step of capturing in order to achieve a rigidly coupled configuration. Therefore, both spacecraft have to be equipped with an appropriate interface, a mechanism for berthing and docking. The unified berthing and docking mechanism (UBDM) is designed as a two-part equipment. It consists of an active interface located on the Servicer and a passive interface on the Client spacecraft.

The two-part UBDM design concept is outlined in Fig. 8 (right) and has two major functions of capturing and

latching the Client's passive docking part. The active part consists of a capturing cone and a latching motor to move the capturing mechanisms and to permanently latch the passive part of the UBDM for a rigidly coupled spacecraft compound. In the latched position the induced force is sufficient to hold the Client in close contact with the Servicer. When using the motor in the reverse direction, the passive part will be unlatched and provided with a driving impulse that allows him to leave the docking cone.

4.1.5. Rendezvous Sensor Package and Illumination

During rendezvous the Servicer has to be maneuvered from far formation flight into the close range of the Client. Fig. 9 gives a brief overview of the sub-phases and the hold points that are mandatory for a rendezvous approach to a non-cooperative satellite. The Servicer reduces the distance to the Client via several Hohmann-like orbit maneuvers ending at distinct hold points. The final approach to the mating position is typically performed via an appropriate v-bar or r-bar maneuver depending on the capture strategy.

Starting from far formation flight, the Servicer reduces the phase angle to the Client. In this phase the Servicer relies still on absolute navigation. The phasing terminates at the Rendezvous Entry Gate (REG).

During far range rendezvous the Servicer is brought from the Rendezvous Entry Gate to the safe point in the range of the Client. If the relative navigation is based on camera images, at least one intermediate hold point (Far to Mid Range Transition Point - FMTP) is required for a controlled switch-over from the far range to the mid range cameras.

If a berthing or docking to a non-cooperative or maybe even unknown target has to be performed, a fly-around is conducted at the Inspection Point (IP), followed by a motion estimation of the target at the Pose Estimation Point (PI). Afterwards the close range rendezvous is started with an orbit maneuver from the safe point to the close hold point (Mid to Close Range Transition Point - MCTP). At the close hold point the cameras have to be switched from mid range to close range (if applicable). From the close hold point the final approach to the berthing or docking box is performed via a straight line trajectory (v-bar manoeuvre). During the final approach the Servicer has to be kept board-autonomously within a pre-defined approach corridor. If the approach corridor is violated, a collision avoidance maneuver has to be initiated board-autonomously. The close range rendezvous ends at the hold point at the berthing / docking box called mating point (MP).

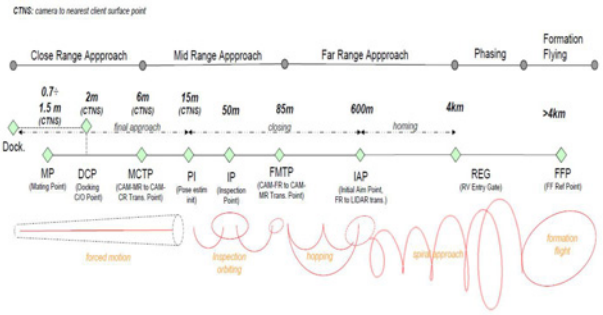

Figure 9. Rendezvous and departure approach

Depending on the operational phases of the approach different sensors will serve as primary sensor. The rendezvous, docking and berthing (RVDB) sensor package consists of the following individual sensor arrangements: 2 LIDAR heads, 2 RADAR, 2 far range mono cameras, 1 mid range stereo camera, 1 close range stereo camera, and 1 docking mono camera.

For formation flying and phasing the far range mono camera is supposed to serve as the primary sensor which provides line-of-sight estimations. From a range less than 700m this role will be switched to the LIDAR head which is expected to deliver additional range information and later on a pose estimation of the Client spacecraft. In these phases a combination of RADAR and mid and close range cameras will be for monitoring and plausibility checking purposes only. The visual inspection of the Client spacecraft will be performed with the mid-range camera, the docking with the docking camera.

Taking redundancy considerations into account all primary sensors are designed twice. Additional to that a Relative-GPS receiver is planned to serve as a safety sensor. In case of malfunction of a sensor the RGPS could deliver line-of-sight and range information, perhaps also pose estimations.

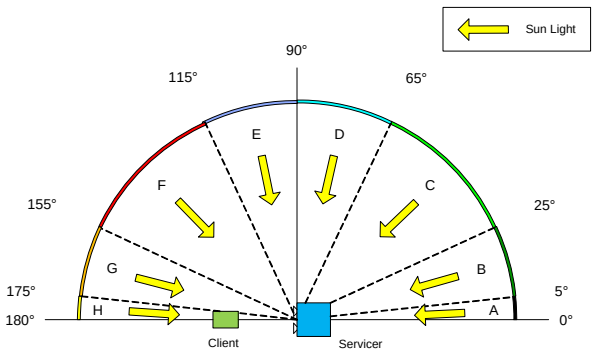

Figure 10. Sun light conditions for optical sensors

Depending on the illumination conditions during pose estimation, final approach or berthing an additional target illumination might be required. Fig. 10 shows potential illumination conditions arising from different sun constellations. Under difficult illumination conditions like back-light or complete darkness an artificial illumination source seems to be mandatory to

produce reliable results from the cameras. For this reason there are two different target illumination systems available for the close range camera and the manipulator camera.

4.2. Surrogate Satellite (Client) Spacecraft

The Client satellite is designed to act primarily like a non-cooperative, tumbling satellite. In addition, it shall have control over the rigid coupled stack during de-orbit maneuvers and the final preassigned and well-defined re-entry maneuvers at the end of the lifetime. Acting as a substitute of a malfunctioned spacecraft out of control and in need of servicing the Client has to have the ability to execute an artificial tumbling. But at any time the Client must be able to release the tumbling motion and stabilize itself. .

The Client spacecraft simulates the multitude of characteristics of a spacecraft in need of servicing and provides the interfaces that are necessary to prove the required Servicer functions such as far range, rendezvous and fly-around, flight maneuvers in coupled configuration, docking, berthing and in-orbit servicing tasks.

The overall baseline design of the Client is shown in Fig. 6. This satellite concept resembles a regular octagon with its edges chamfered such that in addition to the 8 main circumferential areas 8 additional small surfaces are present. Seven of these eight main circumferential areas are covered with solar array cells. The nadir facing main area is reserved for the allocation of the combined nadir S-Band antenna / magnetometer boom. The small circumferential areas are used as thermally radiating areas.

5. CONCLUSIONS

Nowadays satellites should be able to de-orbit themselves but many don't because of a malfunction or lack of fuel. As long as a maintenance or repair of satellites can not be performed it is essential to remove uncontrollable satellites somehow. Otherwise such satellites could get instable over the time; some of them may even start to tumble. Out of control they may become a hazard for other spacecraft.

In general, satellites which are not able to remove themselves from their operational orbit for whatever reason are just given up. Scenarios as DEOS shall proof and demonstrate that current robotic technologies has reached a level of readiness to serve malfunctioned satellites in an appropriate manner. A successful demonstration of DEOS technology and capture concepts will open up a broad range of new on-orbit servicing abilities. Even spacecraft design and operation may take a new direction taking refuelling, repair and upgrade services into consideration. DEOS shall show the possibility to repair, refuel and re-turn spacecraft in the sense of a whole on-orbit service application field.

6. FINAL NOTICE ON THE PROJECT

The DEOS project is performed on behalf of the Space Agency of the German Aerospace Center DLR funded by the Federal Ministry of Economy and Technology within the framework of Germany's National Space Program. Taking a feasibility study of the DEOS mission and system concept into account, the program is on the way to explore and define the overall detailed mission and to develop a preliminary technical system design (ground & space segment) for mission preparation.

Since January 2010 a preliminary Design Definition Phase (Phase B) is in progress performed by the space companies EADS Astrium GmbH, Kayser-Threde GmbH, OHB-System AG and SpacheTech GmbH. Technical support is given by DLR's Institute of Robotics and Mechatronics, Jena-Optronik GmbH, von Hoerner & Sulger (vH&S).

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