Deutsche Orbitale Servicing Mission (DEOS) - Phase A

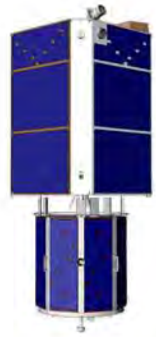
De-orbit configuration

The DEOS mission has been initiated by the German Aerospace Center DLR in order to demonstrate

- rendezvous with and berthing of a non-cooperative, tumbling spacecraft by means of a manipulator system accommodated on a servicing satellite
- docking of a cooperative spacecraft via a dedicated docking device
- performance of servicing tasks while in coupled configuration
- execution of a controlled de-orbiting / re-entry of the two spacecraft in a coupled configuration at the end of the mission

As the overall mission and system prime during Phase A and leading a team of German small companies and scientific institutes, SpaceTech worked out a mission concept and demonstrated its feasibility by

- establishing a feasible scenario for different flight maneuvers, i.e. far and close range rendezvous as well as fly-around maneuvers, including the definition and analysis of adequate rendezvous sensors
- defining and optimizing a realistic experiment program for a one year mission under consideration of environmental conditions and progressively increased experiment complexity
- establishing a technological baseline both, in terms of overall mission implementation and the design of the servicing and client spacecraft, referred to as Servicer and Client, respectively



Stack configuration (during launch, early orbit phase and first experiments)

Mission Overview

The DEOS space segment as elaborated during Phase A consists of a Servicer and a Client spacecraft being injected together into the initial low Earth near polar orbit on one launcher. The Client spacecraft is designed to simulate the multitude of characteristics of a spacecraft in need of service. The Servicer tasks comprise the control of the constellation flight, rendezvous and fly-around, docking, berthing and in-orbit servicing.

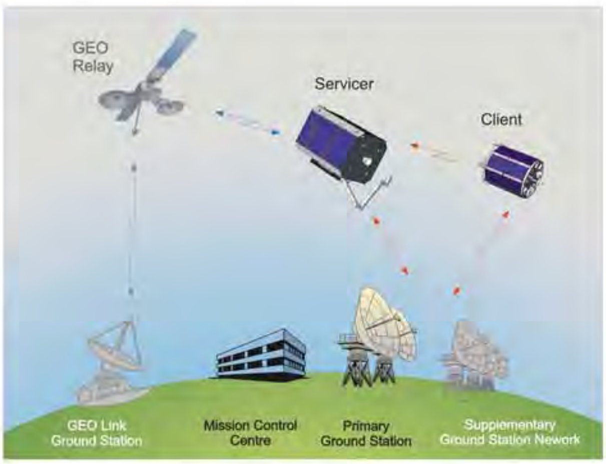
Port coupled configuration (after berthing and docking)

The ground segment consists of the mission control center and the primary ground station network, temporarily amended by an adequate supplementary ground station network during critical demonstration periods. Each spacecraft maintains a direct link to ground. Furthermore the Servicer is able to receive Client telemetry data for board-autonomous mission supervision purposes. Additional communication via geostationary relay satellites and their operating ground stations is intended to be utilized depending on the availability of such system.

Arm coupled configuration during berthing

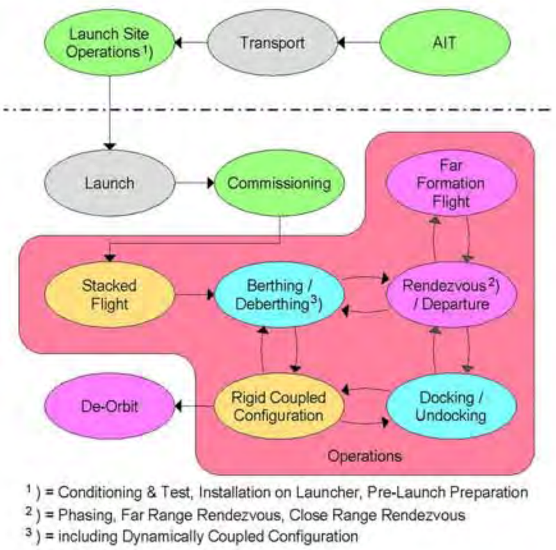
DEOS Phase A main mission parameteres

Mission Characteristics		Comment
Reference Launcher	Dnepr, Rockot	Space segment designed to be compatible for both launchers
Injection Orbit	600 km	Operating altitude will be stepwise reduced over the mission life time to 400 km. From this final orbit altitude the re-entry will be initialized.
Inclination	85° … 90°	87° reference for mission and space segment design
Eccentricity	0	Circular orbit
Orbit / Maximum Eclipse Period	96.7 min / 35.5 min @ 600 km 92.6 min / 36.1 min @ 400 km	Most favorable power conditions at higher altitudes, i.e. during the first part of the mission
LTAN Drift	~1.37° / day @ 87° / 600 km ~1.41° / day @ 87° / 400 km	Symmetrically identical illumination conditions approximately all 4.3 months.
Ground Station Network	Weilheim, Kiruna, Svalbard, Fairbanks, Inuvic	Continuous polar coverage at 600 km, short contact gaps at 400 km.



DEOS mission concept

Mission Implementation



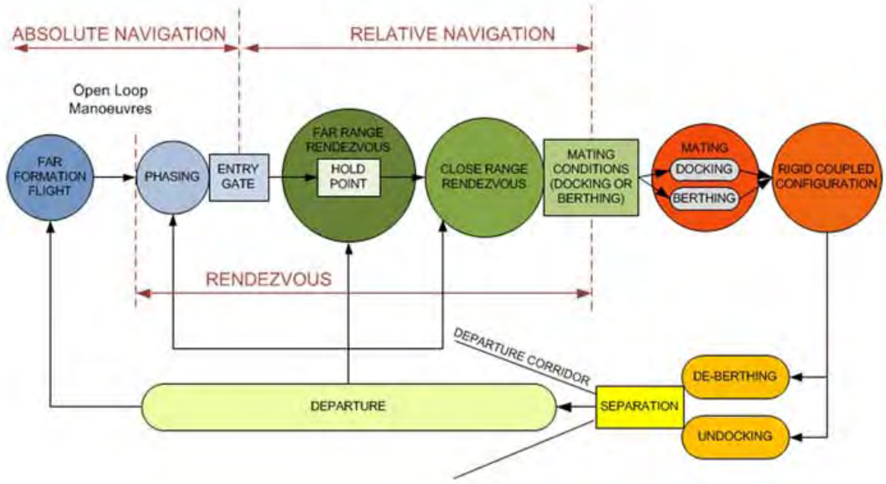
Main operational phases

After the separation of the Servicer/Client stack from the launcher upper stage and an initial commissioning the experiment program will be started, finally ending with the re-entry of the coupled configuration at the end of the mission. Except for initial experiments in the stacked launch configuration and the final re-entry itself, all experiment series will be executed repeatedly under different illumination and communication conditions, increasing the complexity over the course of the mission. The safe flight approach and departure of the Servicer to and from the Client form an essential part of the overall experiment sequence. The structuring of the approach and departure strategy has been elaborated and dynamically analyzed in its individual steps during Phase A.

Two principally different basic navigation methods, absolute and relative navigation, will be applied for all approach and departure /retreat maneuvers.

During absolute maneuvering the Servicer does determine position and attitude with GPS and star cameras, the position of the Client via information received from ground. While the deviation of the Servicer's own position is only dependent on the accuracy of the used receiver, the knowledge of the Client's position onboard the Servicer during periods without ground contactsdepends on the accuracy of the received position data superposed by the difference in external forces on both spacecraft as well as the propagation of failures in the relative speed. Absolute navigation will be used during far formation flight and phasing until arriving at the entry gate.

During relative navigation, the navigation algorithms onboard the Servicer for approach and departure/retreat rely entirely on direct measurements of distance and direction relative to the orbit vector of both satellites using the Servicer's cameras and LIDARs. The accuracy of the measurements depends on the characteristics of the used sensors and the length of potential illumination or field-of-view driven outages between measurements. Relative navigation is used for all rendezvous operations in far and close range and ends when conditions in terms of distance and stability for berthing or docking are fulfilled.

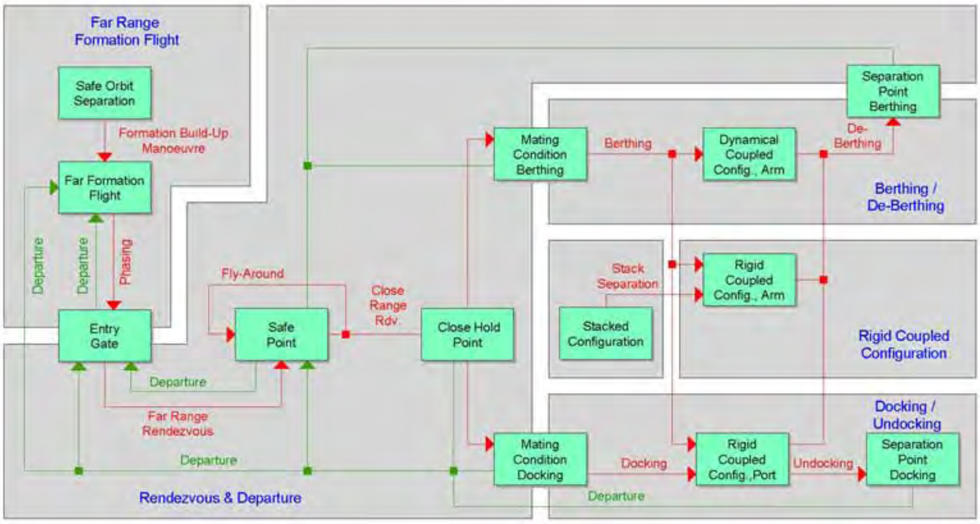


Approach and departure generic concept

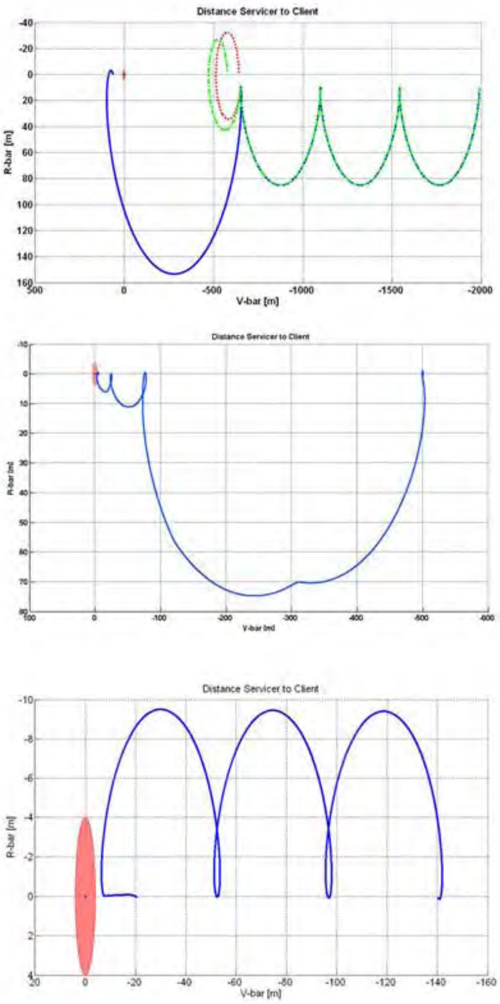
Experimental Program

During the Phase A study an experiment/demonstration program has been elaborated demonstrating the feasibility of realizing the required mission goals within a mission time of less than 1 year. The demonstration program established consists of the following individual demonstration groups:

- Execution of flight maneuvers
  - Far formation flight of Servicer and Client
  - Rendezvous of Servicer with Client using absolute and relative navigational means
  - Targeted departure of Servicer from Client
  - Abort to a safe position at any point of a flight maneuver
  - Fly-around of the Servicer around the Client
- Berthing including the individual steps of close-range formation flight, grappling of the non-cooperative Client with the Servicer manipulator system, stabilizing of the coupled configuration and fixation of the Client via the unified docking / berthing adapter
- Docking and undocking of the Servicer with the cooperative Client
- Flight maneuvering with rigidly and dynamically coupled Servicer/Client configurations
- Execution of service and maintenance tasks at the Client, e.g. fueling and electronic unit exchange
- Execution of de-orbit maneuvers in the rigidly coupled configuration and re-entry at the end of the mission.



Experiment states and transients



Examples of approach strategies worked out: phasing from 2 km to 500 m (top), camera based approach from 500 m to 5 m (mid), collission avoidance maneuver (bottom)

Guidance, Navigation and Control (GNC) Simulations

For all major flight phases in DEOS mission scenario simulations have been performed demonstrating the viability of the overall experiment program with respect to the accommodated sensor package and illumination conditions. In particular the execution of the mission with an optical system, consisting of stereoscopic far range, mid-range and close range cameras, proved feasible, although with tight margins and strong impact on mission planning. The final approach before reaching mating conditions for berthing or docking has to be split when only relying on optical systems. Including an active LIDAR allows for a significant improvement in mission planning flexibility and robustness of the final approach.

Berthing and Docking Simulations

For the grasping of a tumbling satellite an algorithm was worked out based on a combination of multibody dynamics, nonlinear parameter identification, nonlinear optimization and nonlinear control theory. In simulations the feasibility of such complex task was demonstrated.

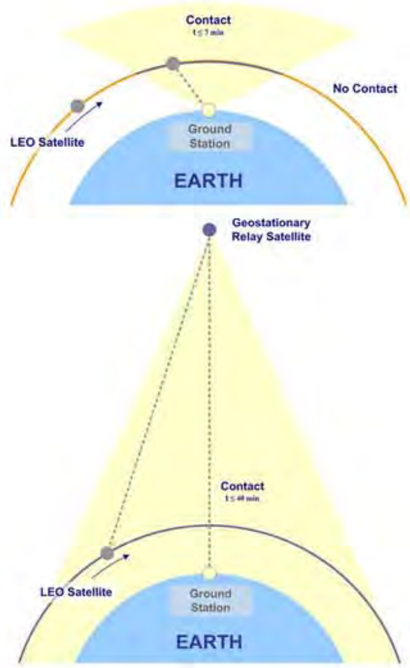
The viability of the design and feasibility of docking between Servicer and Client not only for the nominal case but also for misaligned approach cases was demonstrated by respective contact dynamic multibody-simulations using the Polygonal Contact Model (PCM).

Communication Concept

Communication with the DEOS spacecraft poses a specific challenge for the implementation of the DEOS mission. During the execution of the demonstration program a great-as-possible availability of communication access, partially under real-time conditions (interactive experiments, tele-presence operations), is required. In accordance with the express request of the customer, the feasibility of the demonstration program has been evidenced by setting up consecutive experiment sequences with the exclusive use of a ground station network. In addition the improvement of the mission operations concept in terms of flexibility and robustness has been examined when amending this basic concept with the use of a geo-stationary relay satellite.

Both spacecraft provide bi-directional S-band links to ground. In order to improve the safety, in particular the capability of the Servicer to predict and avoid collisions, an additional on-board receiver on the Servicer spacecraft allows to listen into the telemetry downlink of the Client spacecraft and evaluate its attitude and position data.

For the communication via a relay satellite the Artemis and EDRS (both ESA), TDRS (NASA), DRTS (JAXA) and several commercial communication satellites have been subjected to an evaluation analysis with EDRS and Artemis proving the most promising candidates in terms of availability, data throughput and real-time capabilities.



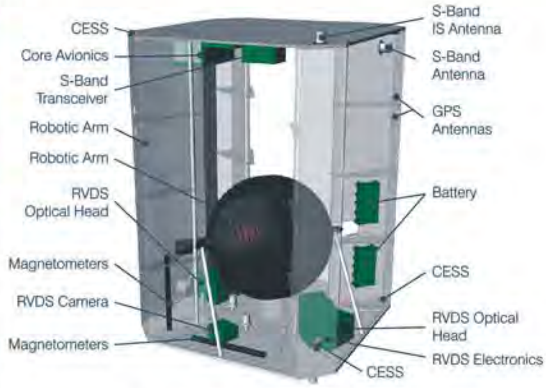
Direct and relayed communication concepts

DEUTSCHE ORBITALE SERVICING MISSION

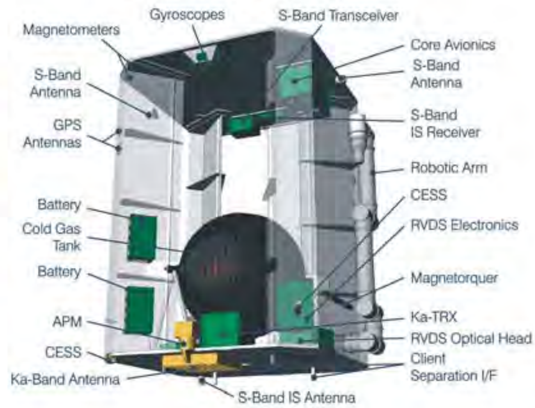
Space Segment Implementation

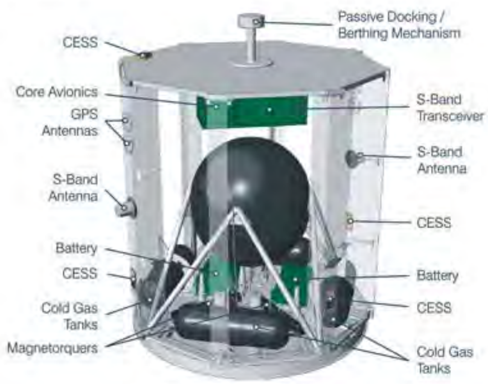
Physical Properties			
Dimensions	Length: 2600 mm / Width: 1700 mm / Height: 1800 mm		
Mass	Dry: 672 kg	Cold Gas: 114 kg	Total: 786 kg
Thermal Control			
Type	Passive system using thermistors and heaters in combination with on-board thermal control application software		
Power System Characteristics			
Power Bus Type	Unregulated 28 V (26 ~ 33.6 V)		
S/A Regulator	Sequential Shunt Regulator		
Avg. Satellite Power	280 ~ 700 W (sun-to-orbit angle dependent)		
S/A Cells	GaAs Triple Junction arranged on 4 solar array panels with 36, 35,35 and 26 strings of 20 cells, respectively		
Battery	Lithium-Ion	Name Plate Capacity	4 x 24 Ah
Attitude & Orbit Control			
Type	Three axes stabilized LVLH		
Sensors	Coarse Earth/Sun Sensor Magnetometer 2 Star Camera Heads Gyroscope GPS Receiver	Actuators	Magnetorquer (3-axes) Cold Gas Propulsion
S-Band Communication			
Uplink	BPSK / 256 kbps Omni-directional	Downlink	BPSK / 4 Mbps 2 W RF Power Omni-directional
Ka-Band Communication			
Forward	256 kbps / BPSK or QPSK High gain directional (2°)	Return	4 Mbps / BPSK or QPSK 15 W RF Power High gain directional (2°)
Payloads			

- Instrument Control Unit (ICU)
- Camera system and LIDAR for relative navigation
- Manipulator system consisting of arm joints, grapple mechanism, stereo camera and lighting
- Active part of the unified docking & berthing mechanism including a docking camera
- Lighting



Servicer Satellite





Client Satellite

Physical Properties			
Dimensions	Length: 1300 mm / Width: 1300 mm / Height: 1900 mm		
Mass	Dry: 289 kg Total: 429.5 kg	Cold Gas: 14.5 kg	Hydrazine: 126 kg
Thermal Control			
Type	Passive system using thermistors and heaters in combination with on-board thermal control application software		
Power System Characteristics			
Power Bus Type	Unregulated 28 V (26 ~ 33.6 V)		
S/A Regulator	Sequential Shunt Regulator		
Avg. Satellite Power	120 ~ 240 W (sun-to-orbit angle dependent)		
S/A Cells	GaAs Triple Junction arranged on 7 circumferential solar array panels with 7 strings of 20 cells each		
Battery	Lithium-Ion	Name Plate Capacity	2 x 24 Ah
Attitude & Orbit Control			
Type	Modes in accordance with demonstration program: • Three axes stabilized LVLH • Free drifting (i.e. attitude control deactivated) • Spin stabilized (spin axis and speed settable) • Tumbling (tumbling axis and nutation angle settable)		
Sensors	Coarse Earth/Sun Sensor Magnetometer Gyroscope GPS Receiver	Actuators	Magnetorquer (3-axes) Hydrazine Propulsion Cold Gas Propulsion
RF Communication (S-Band)			
Uplink	BPSK / 256 kbps Omni-directional	Downlink	BPSK / 256 kbps 2 W RF Power Omni-directional
Payloads			

- Holding devices (handles, grappling ring) supporting the grappling by the Servicer manipulator grapple mechanism
- Passive part of the docking and berthing mechanism including LED light pattern for active support of the docking by the Servicer satellite

The DEOS Phase A was performed by SpaceTech GmbH with support of the subcontractors Institute of Robotics and Mechatronics of the DLR (Oberpfaffenhofen), von Hoerner & Sulger (Schwetzingen), the Chair of Astronautics of the Technical University of Munich and the Institute of Flight Mechanics and Control of the University Stuttgart.

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