KoSBeR Annual Report 2016

Konzeptentwicklung Satelliten und Bemannte Raumfahrt Jahresbericht 2016
Bremen, 6th February 2017

Deutsches Zentrum für Luft und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Institut für Raumfahrtsysteme
Systemanalyse Raumsegment (SARA)

Volker Maiwald
Andy Braukhane
Claudia Philpot

Robert-Hooke-Str. 7
D-28359 Bremen
Telefon 0421 24420-251
Telefax 0421 24420-150
E-Mail mailto: Volker.Maiwald@DLR.de
Internet http://www.dlr.de/irs/
PREFACE

According to some, space is the final frontier. Frontier for exploration and frontier for humanity to go beyond its limits, testing out its potential. The possibilities of space and its exploration are a continuous topic of popular media, especially cinema movies. Space exploration is a dream of many and has been for centuries. Even now there are many who dream to one day take a step on Mars for instance. These dreams can drive us to excellence. But it cannot stop with dreaming.

Many mistake a dream for the truth and think these dreams show us what is possible. That is sadly not so. Dreams can be the start. After the dreams there have to be discipline, diligence and dedication to make these dreams become reality. And one great place to help dreams become reality is KoSBeR.

One of KoSBeR’s assets is its diversity. While it is challenging to work in an environment of such a broad scale, it goes along with the gain of a lot of experience and a wide set of possibilities. Our topics in 2016 have been as usual anything relevant for space, i.e. exploration probes, satellites for Low Earth Orbit (LEO), lander missions or anything related to human spaceflight.

We engaged in research regarding future human spaceflight beyond the current operation of the International Space Station (ISS) contributing in technical analysis to DLR’s “Orbital Hub” concept, developed here in Bremen.

Design and development for a new optimizing method and tool to be used for gravity-assist sequencing of low-thrust missions has been successfully conducted this year, which has been a priority for me.

On a more practical side, the team was also involved directly with two missions. First, Eu:CROPIS, DLR’s flagship mission. KoSBeR is handling the operations definition for the mission. Second, TechnoSat where KoSBeR contributes the SOLID payload, designed to measure space debris impacts on orbit.

There have been a number of personnel changes, with team members coming and going, some only temporarily, some permanently.

Ahead of us lie several challenges, e.g. supporting the preparation of a new line of satellites at the institute, S²TEP, and of course the launch of Eu:CROPIS and TechnoSat along with further refinement of the Post-ISS concepts by international cooperation. So KoSBeR stays to be one of the most interesting spots of contribution to the future of astronauts.

Obviously, also KoSBeR is not working isolated on its own, but first of all within the team of SARA. I thank all our colleagues for the great work throughout this year and of course also all our partners and friends from academia and industry.

Volker Maiwald, December 2016
Content

PREFACE .................................................................................................................................................... 4

KoSBeR PROFILE ....................................................................................................................................... 6

THE KoSBeR TEAM ................................................................................................................................... 8

KoSBeR RANGE OF SERVICES ................................................................................................................... 9

RESEARCH AND RESULTS ....................................................................................................................... 10
  Demonstrators for Conversion, Reactor, Radiator and Thrusters for Electric Propulsion Systems
  (DEMOCRITOS) .................................................................................................................................. 10
  Gravity-assist Optimization for Low-thrust Trajectories (GOLT) ........................................................... 11
  Orbital Hub Concept .......................................................................................................................... 12
  Solar Generator Based Impact Detection (SOLID) ................................................................................ 15

PUBLICATIONS ........................................................................................................................................ 16

KoSBeR IN NUMBERS ............................................................................................................................. 18

OUTLOOK TO 2017 ................................................................................................................................... 20

NOMENCLATURE .................................................................................................................................... 21
KoSBeR PROFILE

KoSBeR's activities are manifold and range from system studies over mission analysis to support and conducting of Concurrent Engineering studies. Furthermore we are also involved in the current and future space missions of the institute in different capacities.

The majority of studies within KoSBeR is focused in the area of feasibility analysis, i.e. Phase 0/A of a space mission. The primary subjects of KoSBeR's feasibility studies are orbital structures like satellites, exploration probes and human spaceflight. Usually the analysis involves several if not all sub-systems, depending on relevance. Interfaces are defined, budgets, e.g. mass and power, are used to evaluate a feasibility of a new concept or credibility of concepts from external sources.

Currently, a particular relevant field of study is the continuation of human spaceflight after the decommissioning of the International Space Station (ISS), shortly labeled as Post-ISS. The team is investigating and developing various concepts also in international cooperation with industry and space agencies alike, e.g. Airbus D&S and JAXA. Smaller activities involve the review of missions beyond LEO. Another subject of analysis are nuclear powered spacecraft for crewed and non-crewed missions around Earth and beyond, see Fig. 2 for an overview of possible applications.

One further field of research is mission analysis and trajectory optimization. These allow the determination of mission key figures, e.g. contact times between ground stations and a spacecraft or propellant demand. Besides the application of existing methods KoSBeR is also engaged in developing new methods.

Space debris is a major concern for successfully operating spacecraft, particularly in LEO. Impact of even just microscopic debris can cause catastrophic failure of a spacecraft. Therefore space debris mitigation and detection is a major subject of KoSBeR.
Next to the mere theoretical work, this relevant topic also lead to practical activities, e.g. the development of SOLID, which is to be launched onboard TechnoSat in 2017 as payload, see Fig. 2.

With the help of SOLID actually measured debris data can be used to update existing models for debris impact prediction and thus help to better understand the debris environment in LEO and to improve debris protection of spacecraft.

KoSBeR is also supporting DLR’s missions with preparation of e.g. operations and radiation analysis of Eu:CROPIS and S²TEP.

Furthermore KoSBeR regularly leads and supports Concurrent Engineering (CE) Studies of DLR.

Figure 3:
Close-up view of the SOLID solar panel, containing the embedded debris detector (right).
THE KoSBeR TEAM

Dominik Quantius
Team Leader
(currently on leave)

Volker Maiwald
Deputy Team Leader

Claudia Philpot
Researcher

Andy Braukhane
Researcher
(entry date 1st Dec. 2016)

Daniel Digiloramo
Master Thesis Student
(April - September 2016)

Nandish Kuntikal Doddi Mahadevaiah
Master Thesis Student
(June – December 2016)

Hauke Hansen
Master Thesis Student
(since September 2016)
The KoSBeR team is focused on pre-development activities. These are enhanced and supplemented by prototype engineering, breadboarding and experimentation.

We are offering the following competencies and activities for customers, partners and academia:

- Feasibility, trade-off and system analysis of space systems (landers, interplanetary probes, satellites, human spaceflight) down to component level, based on key figures like e.g. launch mass, power demand, configuration and costs.
- Mission analysis regarding satellite orbits (incl. figures of merits like e.g. contact times and coverage) and trajectory optimization for mission concepts and all later mission phases.
- Conducting Concurrent Engineering studies with various subjects, e.g. spacecraft design, mission architectures, subsystem architecture (50+ studies experience), s. Fig. 4.
- Debris impact risk analysis and debris mitigation/ protection.
- Solicitation, preparation and supervision of experiments on ISS, including the respective administrative and agency activities.
- Definition and completion of satellite operations products like operations concepts, user manual, procedures and FDIR concepts, e.g. for Eu:CROPIS.
- Operations support during satellite Assembly, Integration and Test (AIT) campaigns.
- Managing of and participating in EU and other large scale projects, respectively their solicitation.
- Preparation and application of experimentation and test rigs, e.g. for vacuum and thermal tests.
- Preparing and conducting analogue test site missions.

The field of work usually focuses exclusively on space systems, but our skills have been applied to other branches of engineering facing peculiar challenges, e.g. deep-sea robotics.

KoSBeR is embedded into the System Analysis Space Segment (SARA) department and the Institute of Space Systems and DLR in general, which provides for example:

- The Concurrent Engineering Facility (CEF): The design laboratory of SARA used for the design, analysis and system review of any desired complex system
- The Virtual Satellite software for model based systems engineering
- Simulation software, e.g. STK (see Fig. 5), Matlab
- Self-created software tools, e.g. GOLT
RESEARCH AND RESULTS

This chapter describes in detail the most relevant research activities of KoSBeR (not including confidential projects) and shortly presents important results.

Demonstrators for Conversion, Reactor, Radiator and Thrusters for Electric Propulsion Systems (DEMOCRITOS)

Future missions in low Earth orbit and for lunar and interplanetary exploration are expected to require large space structures. Respectively new structure technologies are needed to allow the establishment of such missions. DEMOCRITOS is an ongoing EU project, carried out by an international consortium aimed at progressing in the development of a modular spacecraft capable of providing power in the Megawatt range.

Background
Goal of the recent work has been the establishment of a testing logic for developing a ground demonstrator. The spacecraft to be is meant to be versatile and capable of dealing with a whole portfolio of missions, e.g. cargo transfers to the lunar surface, asteroid deflection or exploration of Jupiter’s moons.

Method
As a first step to set up the design of the spacecraft structure, mission and respectively structure requirements have been defined. Next the technologies capable of fulfilling these requirements were summarized, analysed and evaluated to formulate a credible and feasible design. The evaluation criteria have been: length, stiffness, strength, mass, packaging ratio, technology readiness level and interfacing capability.

A payload mission to Mars, assuming on orbit assembly and nuclear electric propulsion has been used as example mission.

Results
The mission duration has been defined as 5 to ten years of lifetime and assumed that the demonstrator mission should be conducted in the early 2020s, the actual mission should then occur in 2040 at the latest. The system has been set up as modular, assuming that only one module contains the nuclear components.

The spacecraft is propelled by a cluster of Hall thrusters, 5-20, capable of a specific Impulse between 3000s and 9000s, depending on the actual mission. Overall the power specific mass is required to be below 4kg/ kWe and the reactor should be able to produce up to 3 MW of power. The spacecraft structure should have a specific mass below 40 kg/ m.

Best performing regarding the technology analysis have been the deployable articulated truss and a coilable truss (see Fig. 6).
Gravity-assist Optimization for Low-thrust Trajectories (GOLT)

Gravity-assists (GA) are an established method of gaining “free energy” for trajectory changes and have been used for missions like Voyager, Rosetta and Dawn (see Fig. 8) thus reducing the overall mission $\Delta v$. Often GAs have been the mission enablers, as without the respective propellant savings a mission would not have been possible at all or at least with a reduced performance, due to reduced payload mass.

Similarly low-thrust (LT) engines, typically electrical thrusters, can reduce the propellant mass, due to their specific impulses being usually factor 8 to 10 larger than those of chemical thrusters, i.e. their improved efficiency. This leads to larger payload masses, i.e. mission performance.

Therefore KoSBeR researches methods of combining both means to further reduce propellant masses of space missions.

Background

The state of the art regarding mission optimization usually allows only the optimization of trajectories, whereas the sequence of gravity-assist partners is fed into the optimizer by the mission analyst. This poses the danger that worthwhile of solution candidates are overlooked. Previous attempts of allowing the optimizer to search for a gravity-assist failed due to the complexity of phasing and mission parameters.

Therefore the goal of KoSBeR has been to develop a method for making the GA sequence part of the optimization process. The method was intended to be quick to allow application in CE studies.

Method

The initial step of the work has been the review of existing optimization methods, e.g. the Tisserand Criterion (TC) and the development of a correction term for this energy relation as necessary to apply it for low-thrust. This proofed to disallow the usage of the TC for optimization of low-thrust gravity-assist missions, because the correction term no longer is a state variable, preventing a priori mapping of useful gravity-assists. A different approach had to be established.

Consequently the method employs a heuristic search of a solution space, involving all relevant variables, most importantly the gravity-assist partner as one of them. This allows the optimizer to incorporate the search for an optimal gravity-assist partner into the process, guaranteeing the complete coverage of the search space.

The variables, e.g. total flight time of the mission and flight times of the individual mission segments, or suitable flight time for reaching a given gravity-assist partner, are not completely independent of each other, therefore they have been divided into global variables, which describe the overall mission including its gravity-assist partners and local variables defining a mission segment and gravity-assist properties (e.g. approach velocity). Global variables are used for evolutionary optimization, whereas local variables have to be reinitialized for every iteration.

To allow fast evaluation of a large number of mission candidates, a shape-based trajectory model has been implemented. While this is a low-fidelity model, it can be easily and quickly applied.

Verification of the tool and method have been conducted by recalculating mission with known and existing trajectories and comparing the respective properties like launch date, flight time.
Results
The optimization results have been promising for missions involving one gravity-assist. The optimizer has been able to identify optimal gravity-assist partners independently of the mission analyst. For differential evolution a population size of 50 could already produce an improvement of mission $\Delta v$ of several hundred meters per second. This increased to several kilometers per second for larger population sizes. In the best case this lead to $\Delta v$ improvement of 22% (see Fig. 9).

Furthermore by comparison with a random search, it was shown that using the global variables for optimization in an evolutionary manner, it was determined that these variables, e.g. mission flight time, mission launch date, gravity-assist partner, have a dominant role for this kind of optimization problem.

For multi-gravity-assist mission the method shows potential, but has not lead to mission performing better than those without gravity-assists, which is attributed to the fact that not all variable information could be handed over from one iteration to the next, due to the links of the local variables.

Currently more algorithms and further search space constrains are under review to improve the obtainable results and the overall optimization quality. A step-wise optimization is considered for further refinement.

Orbital Hub Concept

The Orbital Hub is a product from the Concurrent Engineering process applied on the Post-ISS project. The Orbital Hub concept mainly supports the establishment of future programmes in the broader field of human spaceflight to secure ongoing international cooperation and long-term interdisciplinary research and human spaceflight activities in Low Earth Orbit (LEO).

Feedback from scientists, experts, and ISS partners has shown sustained high interest in using the LEO environment on a multi-purpose mini-platform. Orbital Hub represents the highest degree of maturity based on current technologies, operational/logistical systems, current commercial developments and financial aspects.

In addition to the conventional scientific utilisation, the hub should provide complementary payloads for Earth observation, technology demonstration and commercial applications, as well as opportunities for preparation of human planetary exploration.

Background

The ISS is scheduled to operate until 2024 according to programmatic papers. Currently no new contracts or joint ventures of a similar size are established to replace it, while the ISS operation, due to its size, seems too expensive for ISS partners. Governments and agencies search for a solution for a smooth transfer in which to invest and teams of engineers and scientists have the task of tackling a part of the question: How best to continue with space research and space technology development after the ISS utilisation period?

A transition to a new concept without a critical loss of know-how takes 10 to 15 years. Therefore, the conceptualisation regarding technical layout, creating a road map and the development of an ISS follow-on outpost in LEO has to be started now. The Orbital Hub or a similar concept could guarantee a smooth transition from the ISS to future human space activities in LEO and would represent an important step towards long-term human space exploration beyond LEO.
Method
With support of DLR scientists requirements were collected from many research disciplines regarding a future small LEO platform. In a Concurrent engineering (CE) study at the Concurrent Engineering Facility (CEF) in Bremen, strawman payloads were defined, analysed and designed for a base platform and a strongly requested Free Flyer, see Fig. 10. Both platforms together form the Orbital Hub as a possible ISS follow-on human spaceflight research platform in LEO.

In two more CE studies, strongly supported by the institute’s CE Team, the base platform and the Free Flyer were analysed and designed in cooperation with experts from the space industry. Aspects like orbital structure layout and logistics, best location of payloads and secondary demands (e.g. data volume, interfaces, crew, lifetime and costs) were included and the design was completed on a component level, encompassing mass, power and data budgets.

A major design driver has been that once the system and experiments are in orbit, operational costs have to be reduced by, for example, implementing modularity of all experimental equipment, an improved station wireless network and improved data transfer options. Scientific users demand high pointing accuracy and low impacts caused by the crew activities or mechanical parts of the platform. The Free Flyer without crew orbit keeping on both platforms. Particular attention has been paid to design the hardware with respect to existing flight systems, to reduce development time and cost. The requirement is to maintain a crew of three plus possible visitors with at least one module for science laboratories, one module for crew accommodation and associated environmental control and life support systems.

During the end phase of the activities in 2016, possibilities of cooperation between JAXA and DLR were investigated in a workshop, analyzing and reviewing station concepts involving DLR’s components from Orbital Hub and HTV-X and possibly the Japanese Experiment Module.

Results
A lean multipurpose platform with an additional dockable free-flying platform has been selected by the design team as the least costly option.
The Orbital Hub concept would be the core element for modular logistics and distribution, providing docking, servicing and goods (e.g. propellant or experiments) distribution. The Orbital Hub concept is to be assembled and equipped using a minimal number of launches, in its current version three.

The consequence is a much smaller, less complex platform compared with the ISS, see Fig. 11. The design foresees an expandable habitat (e.g. as developed by Bigelow Aerospace and tested aboard the ISS) to cover the life support, some laboratory and crew accommodation functionalities. The Base Platform should also be compatible with simultaneously visiting transport - and crew vehicles. Therefore, a five-point docking node is proposed at one end of the Base Platform. EVAs need a significant amount of the precious crew time for preparation and execution. In contrast to the ISS, the Orbital Hub concept is designed to limit the required EVAs for emergency procedures by placing items externally using solely robotic manipulation.

Since the critical user requirements regarding attitude and disturbances are shifted towards the Free Flyer, the Base Platform is free to roll or yaw a certain amount. This allows for a one-axis rotatable solar panel concept which does not need additional truss structures, as on the ISS, further simplifying the operation and design. The base configuration is thereby free to have the Habitat Module or the Docking Node point into the direction of flight. This enables thrust, either from the docked crew or cargo vehicle, for station keeping and manoeuvres, reducing the need for regular refueling of the platform for orbit maintenance.

The Free Flyer (see Fig. 10) is intended to fly without crew in a safe formation with the Base Platform for e.g. three-month periods before it automatically docks to the platform for a short duration. This allows undisturbed experimentation. Once docked, it can be maintained, reconfigured, stocked up, and the payload transferred for return to Earth. The overall dimensions of the Free Flyer in stowed configuration are optimised to be in line with the envisaged single-launch scenario using Ariane 6-4.
Solar Generator Based Impact Detection (SOLID)

Space debris (SD) and micro-meteoroids (MM) are a threat for space systems. Whereas the MM flux can be assumed as rather constant, the SD environment is highly dynamic and also increasing due to current and past activities in space. Particularly fluxes of smaller particles require in-situ measurements since they cannot be identified and monitored from ground. Currently this data and associated models of the space debris environment, such as the European tool “MASTER”, used to design reliable space systems, require improvement.

Background
To analyze the quantity of space debris and micro-meteoroids in space, particularly within the 100µm to 1mm range, which already is critical for spacecraft but where only little data is available, an innovative in-situ impact detection method called “Solar generator based impact detection (SOLID)” has been developed at DLR in Bremen. SOLID uses solar panels for impact detection. Since solar panels provide large detection areas, this method allows the collection of large amounts of in-situ space debris data. This data can be utilized for model validation.

Furthermore, impact damage can be verified once more to confirm or to refute an impact. Both aspects can significantly improve the quality of model validation by using large amounts of highly reliable data.

Method
The key element of SOLID is the detection matrix made of thin copper lines which are integrated within the polyimide insulation layer between a solar array assembly and the solar panel substrate.

Impacting objects damage the solar array and cut – depending on the particle size – one or several detection lines in both x- and y-direction. Frequent or dedicated conductivity tests of these lines indicate if an object hit the solar array and provide information on the impact location and size due to the number and position of damaged detection lines. Based on retrieved space hardware (e.g. solar panels from Hubble Space Telescope), damage equations have been derived by ESA in the past. These are utilized for estimation of impacting objects.

Results
The concept is patented in Germany and in the U.S. since 2012 and 2013 respectively. It has been tested on ground in 2013, performing hyper-velocity impact tests at the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach Institut, in Freiburg.

In 2016 the SOLID flight model for its first in-orbit verification has been finalized and will be launched as part of the TechnoSat mission by the Technical University of Berlin in early 2017.

The SOLID concept is currently further under development regarding automatic impact detection using satellite housekeeping data, which aims to be tested in-orbit within the frame of the DLR S-TEP mission with a planned launch in 2019. This improved detection mission provides additional temporal information of the impact by analyzing the solar array output voltage profile and enables dedicated and more efficient conductivity tests of the SOLID detection matrix, which eventually further reduces the time-related uncertainties of currently modelled space debris fluxes.
PUBLICATIONS

JOURNAL ARTICLES


CONFERENCE PROCEEDINGS


V. Maiwald, “About Combining Tisserand Graph Gravity-assist Sequencing With Low-thrust Trajectory Optimization”, 6th International Congress on Astrodynamics Tools and Techniques, 14-17 Mar 2016, Darmstadt, Germany

P. M. Fischer, M. Deshmukh, V. Maiwald, D. Quantius, A. Martelo Gomez, A. Gerndt, “Conceptual Data Model – a Foundation for Successful Concurrent Engineering”, 7th International Workshop on System & Concurrent Engineering for Space Applications (SECESA); October 5-7, 2016, Madrid, Spain


REPORTS


INVITED TALKS

V. Maiwald, “Optimierung von Niedrigschubbahnen: Methoden und Herausforderungen”, 18th May 2016, Institut für Automatisierungstechnik, University Bremen
B. Still, R. Schröder, V. Maiwald, “Auftakt nach Mars”; Audi.torium, 22nd November 2016, Neckarsulm

B. Still, R. Schröder, V. Maiwald, “Auftakt nach Mars”; Audi.torium, 23rd November 2016, Ingolstadt

STUDENT THESES


MISCELLANEOUS

Figure 13:
Funding Distribution 2016

KoSBeR IN NUMBERS

Total: 652 k€
Internal: 599 k€ (92%)
External: 52 k€ (8%)

Mission Analysis: 67 k€ (10%)
System Analysis: 533 k€ (82%)
System Analysis: 52 k€ (8%)

Figure 14:
Cooperation with Universities

Total: 6
University Lectures: 1 (17%)
Master Students: 3 (50%)
Finished Master Theses: 2 (33%)
Figure 15:
Publications & Reports

Total: 17
- Main author: 13 (76.5%)
- Co-author: 4 (23.5%)
- Journal Articles: 1 (5.9%)
- Invited Talks: 3 (17.6%)
- Conference Proceedings: 3 (17.6%)
- Reports: 3 (17.6%)
- Proposals: 2 (11.8%)
- Misc: 1 (5.9%)
OUTLOOK TO 2017

KoSBeR’s activities in 2017 aim at continuing current work and also at improving our scientific impact in the aerospace community.

2017 marks a very special year for the Institute of Space Systems in general and KoSBeR in particular. In autumn the first compact satellite, Eu:CROPIS, will be launched. Originally KoSBeR supported the mission with leading the CE study for Phase 0/A and currently we are contributing to it by preparation of its operation, which will continued even through the launch campaign. Once Eu:CROPIS will be in its mission operation phase, KoSBeR will be supporting the pre-development of its successor.

Furthermore SOLID will have its inauguration on Technosat also in 2017, providing new debris measurements. This marks the first usage of a dedicated debris detector on orbit and will hopefully lead to extended usage of similar devices on a broad scale in the future.

Several studies are already planned in the frame of human spaceflight but also beyond and we will also further prepare an ISS experiment in conjunction with a neighbor department (Avionics System).

To further our concept of a habitation laboratory, KoSBeR is preparing a Concurrent Engineering study in cooperation with ESA’s Astronaut Center (EAC) and its partners from the Incubator for Habitation (I4H) initiative.

Also the activities in the frame of the Orbital Hub are aiming at another CE study, focused on the possible collaboration of JAXA and DLR in this field.

Besides these topics, KoSBeR aims to improve its excellence in science by increasing the number of reviewed publications, strengthening its importance and impact in the field of pre-development. Similarly our goal is to improve our rate of third party funding.

Figure 16: The Facility of Laboratories for Sustainable Habitation (FLaSH) in its current layout. Image: Dr. Ondrej Doule (Space Innovations)
## NOMENCLATURE

<table>
<thead>
<tr>
<th>Letter</th>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AIT</td>
<td>Assembly, Integration and Testing</td>
</tr>
<tr>
<td>C</td>
<td>CE</td>
<td>Concurrent Engineering</td>
</tr>
<tr>
<td></td>
<td>CEF</td>
<td>Concurrent Engineering Facility</td>
</tr>
<tr>
<td>D</td>
<td>DEMOCRITOS</td>
<td>Demonstrators for Conversion, Reactor, Radiator and Thrusters for Electric Propulsion Systems</td>
</tr>
<tr>
<td></td>
<td>DLR</td>
<td>German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)</td>
</tr>
<tr>
<td>E</td>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td></td>
<td>EAC</td>
<td>European Astronaut Center</td>
</tr>
<tr>
<td>D</td>
<td>DLR</td>
<td>German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)</td>
</tr>
<tr>
<td>F</td>
<td>FLaSH</td>
<td>Facility of Laboratories for Sustainable Habitation</td>
</tr>
<tr>
<td>G</td>
<td>GA</td>
<td>Gravity-assist</td>
</tr>
<tr>
<td></td>
<td>GOLT</td>
<td>Gravity-assist Optimization for Low-thrust Trajectories</td>
</tr>
<tr>
<td>I</td>
<td>ISS</td>
<td>International Space Station</td>
</tr>
<tr>
<td></td>
<td>I4H</td>
<td>Incubator for Habitation</td>
</tr>
<tr>
<td>K</td>
<td>KoSBeR</td>
<td>Concept Development for Satellites and Human Spaceflight (Konzeptentwicklung Satelliten und Bemannte Raumfahrt)</td>
</tr>
<tr>
<td>L</td>
<td>LT</td>
<td>Low-thrust</td>
</tr>
<tr>
<td>M</td>
<td>MM</td>
<td>Micro-meteroids</td>
</tr>
<tr>
<td>S</td>
<td>SARA</td>
<td>System Analysis Space Segment (Systemanalyse Raumsegment)</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>Space Debris</td>
</tr>
<tr>
<td></td>
<td>SOLID</td>
<td>Solar Generator Based Impact Detector</td>
</tr>
<tr>
<td>T</td>
<td>TC</td>
<td>Tisserand Criterion</td>
</tr>
</tbody>
</table>
DLR at a glance

DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany’s space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation’s largest project management agency.

DLR has approximately 8000 employees at 16 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Goettingen, Hamburg, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

DLR’s mission comprises the exploration of Earth and the Solar System and research for protecting the environment. This includes the development of environment-friendly technologies for energy supply and future mobility, as well as for communications and security. DLR’s research portfolio ranges from fundamental research to the development of products for tomorrow. In this way, DLR contributes the scientific and technical expertise that it has acquired to the enhancement of Germany as a location for industry and technology. DLR operates major research facilities for its own projects and as a service for clients and partners. It also fosters the development of the next generation of researchers, provides expert advisory services to government and is a driving force in the regions where its facilities are located.