DLR-KOMPAKTSATELLIT: A SMALL GERMAN SPACECRAFT DEVELOPED BY DLR FOR SUBSTANTIAL SCIENTIFIC RETURN

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Abstract

In 2007 the German Aerospace Centre (DLR) initiated the DLR-Kompaktsatellit program with the objective to create a small, flexible platform on which future advanced scientific DLR missions could be based. The first mission selected for the Kompaktsatellit program was AsteroidFinder, a mission to characterize the unknown Inner Earth Object (IEO) population in terms of mass, size and distribution. With an estimated total mass of 100-150kg excluding the payload the DLR-Kompaktsatellit is classified as a small satellite, and will be the first satellite above 20kg developed under the management of the department of Satellite Systems (TY) at the DLR Institute of Space Systems in Bremen. The development and later the utilisation of DLR-Kompaktsatellit involves several DLR institutes throughout Germany. The satellite platform is designed using subsystems and units which are both new developments by DLR and commercial off the shelf (COTS) parts procured from German and European industry. The AsteroidFinder mission is envisaged to be launched in 2014, and the project is scheduled to conduct the Preliminary Design Review and enter Phase C during 2011. The development of a small satellite with the scientific return of AsteroidFinder represents a great challenge for the involved parties. However with a highly integrated and innovative team, augmented by the use of modern engineering practices and technologies, it is shown that such challenges can be met within the constraints of small satellite projects, and that the objectives of the DLR-Kompaktsatellit program can be met within the framework of a mission such as AsteroidFinder.

1. INTRODUCTION

Due to advances in the field of miniaturization of electronics and mechanisms, the size and mass of satellites which perform scientific missions are becoming smaller and smaller.

The small satellite class represents a trade-off between the high performance of larger satellites and the low development cost and time of nano/pico satellites. The small satellite class enables missions with a significant scientific return at a lower cost than larger satellites both in terms of launch and development costs. The small satellites achieve their high performance relative to their size by using state-of-the art technology and applying modern engineering methods during the design phase.

2. THE DLR-KOMPAKTSATELLIT PROGRAM

In order to obtain these benefits for in-house R&D projects, DLR initiated the DLR- Kompaktsatellit program in 2007. The DLR-Kompaktsatellit program has the following objectives:

- Establish and maintain an end-to-end system competency for satellite missions within DLR and Germany
- Providing a space-based platform for R&D projects
- Support specific research projects

The objectives will be further discussed in the following sections.

2.1. End-to-end system competency

The DLR-Kompaktsatellit program aims to establish an end-to-end satellite system competency for scientific satellites within DLR and, as a result, Germany. One of the clear advantages by this approach is the opportunity to capture knowledge transfer that would otherwise remain the IP of contractor parties. This ensures that the DLR-Kompaktsatellit series permits easy heritage reuse once the first mission has been launched.

2.2. Space-based platform for R&D projects

The primary objective of the DLR-Kompakt satellite program is to provide a space based platform for DLR research and development projects.

2.3. Support for specific research projects

In addition to the broad objective of providing a space based platform for R&D projects, the DLR-Kompaktsatellite program shall allow for tailoring to specific missions and research projects. In this scenario the mission is dedicated to a specific project or payload.

For this type of mission the advantages of keeping the development and design of both parts of the satellite (i.e. bus and payload) within one organization are increased. Rather than completing the (preliminary) payload design and thereafter assess whether a satellite bus can be procured from industry with the performance required within the constraints of the available budget and schedule, the DLR-Kompaktsatellit program allows to tailor the performance of the satellite bus as the payload design matures, and identify potential design changes to either the payload or satellite bus design which benefits the mission from an overall perspective.

3. THE FIRST DLR-KOMPAKTSATELLIT MISSION

Three candidate missions for the first DLR-Kompaktsatellit mission were evaluated in 2007 at the newly founded Institute of Space Systems in Bremen, Germany. At the end of this evaluation, the AsteroidFinder proposal was selected to be the first DLR-Kompaktsatellit mission. The mission is managed by the Institute of Space Systems, which is also responsible for developing the satellite bus. The payload is developed by the Institute of Planetary Research, DLR and the ground segment is handled by the German Space Operations Center (GSOC).

3.1. The AsteroidFinder Mission

Inner Earth Objects (IEOs) are objects whose orbit resides completely inside the Earth's orbit around the Sun. IEO's represent a potential risk of collision with the Earth, due to possible disturbance of their orbits by other celestial objects (e.g. Venus or Mercury). IEO's are generally not visible by Earth-based telescopes due to the brightness of the sky at the solar elongation angles necessary for observation. Traditional asteroid surveys conducted by ground-based telescopes therefore focus primarily on Near Earth Objects (NEOs) with aphelions outside the orbit of the Earth (which can be seen performing the surveys during the night). The difficulties of detecting IEO's from ground drives the need for a space borne telescope in order to detect and characterize this population population.

Apart from the scientific return, the objective of the first DLR-Kompaktsatellit mission is the development of the complete end-to-end system competencies and engineering approach for a satellite mission within a newly founded institute. While many standards are readily available, e.g. the ECSS, the tailoring of these to meet the needs of a program such as the DLR-Kompaktsatellit is considered a major and important objective of the first DLR-Kompaktsatellit mission. The mission design of the follow-up missions in the DLR-Kompaktsatellite program will takes its foundation in the procedures established during the AsteroidFinder mission.

The first mission includes the development of a new onboard avionics system and the architectural design and procurement of the power subsystem. The first mission therefore serves as a technology demonstration of these elements as well as the validation of the overall platform design. An important output of the first mission is the characterization of the platform performance in all areas, which allows to update the margin philosophy and design approach for future missions.

3.1.1. Mission Definition

The AsteroidFinder mission aims to characterize the population of NEOs and in particular IEOs and Atens in terms of:

- Number of objects
- Orbital distribution and orbital parameters
- Size distribution

Asteroids shall be recognizable through their apparent motion against the fixed star background on subsequent images taken by the AsteroidFinder Instrument flying onboard the satellite bus platform. The observations shall enable the determination of short-arc orbits, whose accuracy shall be adequate to recover the detected objects within one month from ground-based follow-up observations, or from AsteroidFinder itself

3.1.2. Mission Description

The main science objective of AsteroidFinder is to discover a significant number of IEOs, determine their orbits and estimate their sizes. As seen from 1 AU, these objects are located at small solar elongations, and therefore the main search area for AF is the region of interest (RoI) defined by –60° ; –30° and +30°; +60° in sun-centered ecliptic longitude and from +40° to –40° in sun-centered ecliptic latitude. Figure 1 shows the positions of all objects from the IEO model population given by [1] down to a size of about 100m and over a period of 5 years, with the RoI overplotted as red rectangles. The inner limit in sun-centered longitude (–30° and +30°) is driven by practical design limitations (baffle design and telescope straylight rejection properties) and by the increased sky background brightness due to the Zodiacal Light. The outer limits in longitude and in latitude are chosen to maximize the search efficiency and so as not to interfere with the major NEO ground- based surveys.

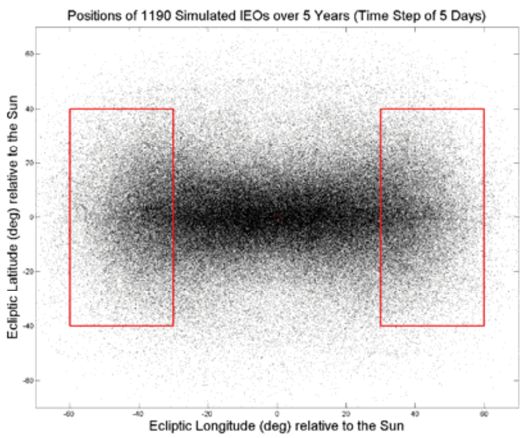

Figure 1: Region of Interest

4. SPACE SEGMENT OVERVIEW

The space segment of the AsteroidFinder mission consists of a single satellite, the main elements of which are depicted in Figure 3. The satellite consists of a bus compartment, a payload compartment, deployable solar panels, a sunshield and finally the cold radiator and MLI encapsulating the payload compartment.

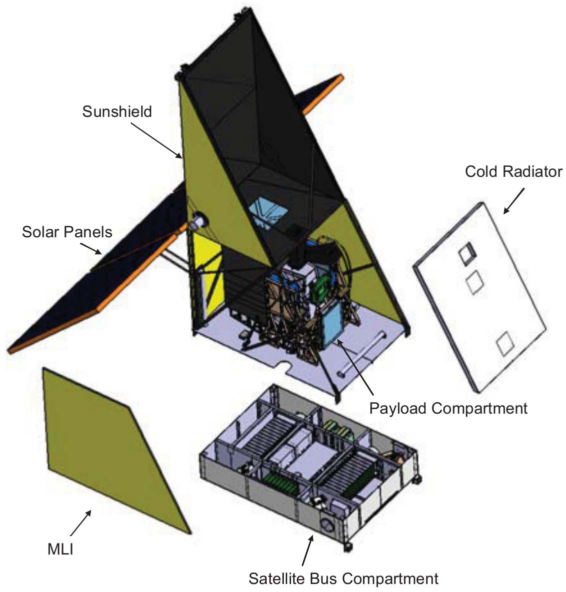

Figure 3: Main elements of the AsteroidFinder Space Segment

A functional diagram of the AsteroidFinder Space Segment can be seen in Figure 2.

The majority of the satellite bus units are located in the bus compartment, with the exception of units which must be located elsewhere (e.g. magnetorquers, magnetometers and sun-sensors).

The payload data processing and power conversion units are located in the satellite bus compartment, and all remaining payload units are located inside the payload compartment.

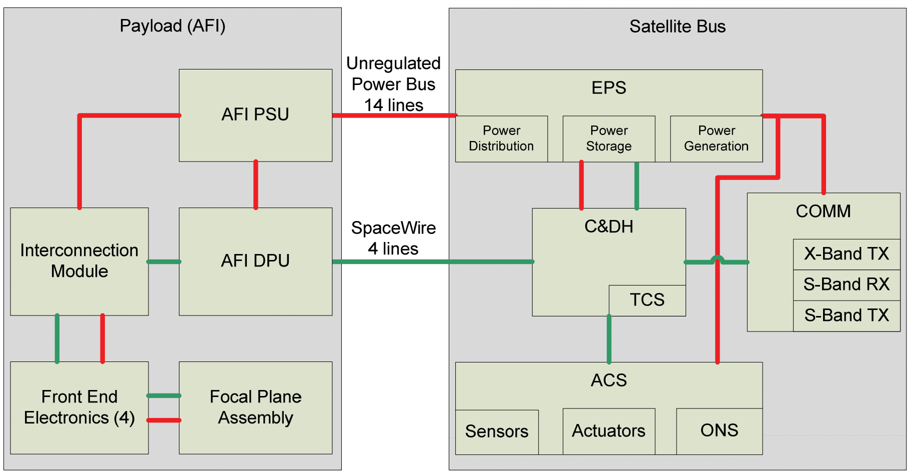

Figure 2: Space Segment Functional Diagram

The solar panels are stowed during launch, and deployed at a 45 degree angle after spacecraft separation. The stowed configuration of AsteroidFinder can be seen in Figure 4.

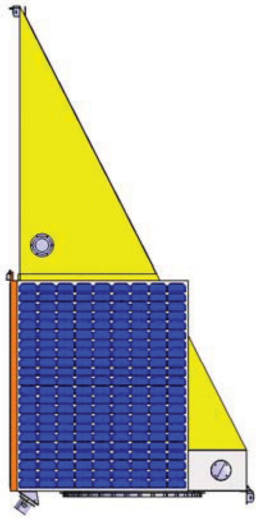

Figure 4: AsteroidFinder in stowed configuration

The sunshield is constructed of MLI, and the inner layer consists of a material which has a low reflectivity. The sun shield has an angle of 27 degrees with respect to the telescope boresight. The sunshield ensures that direct sunlight does not enter the telescope aperture during nominal operations.

4.1. Bus-Payload Interface

The main electrical interfaces between the payload and the satellite bus consists of 4 cold redundant SpaceWire connections each operating at 10 Mbit/s and 14 separate power switches, providing an unregulated voltage between 19-34V with a total of 150W during nominal operations. The mechanical interface between the instrument and the satellite bus consists of three quasi-isostatic mounts.

5. SATELLITE BUS OVERVIEW

The following sections describes the configuration of the satellite bus which has been designed for the AsteroidFinder mission, and explains in brief the major trade-offs which has been performed during the Phase 0,A and B of the project.

The satellite bus contains the standard elements of a small satellite without a propulsion subsystem. The satellite bus provides the following primary functions:

- Primary power generation,storage and distribution
- Attitude control
- Storage and forwarding of payload data
- Telecommanding and telemetry handling and interface to ground.
- Thermal control
- Navigation and guidance
- Onboard autonomy

The primary performance parameters and characteristics are summarized in Table 1.

<table>
<tr><th colspan="4">AsteroidFinder Satellite Bus Characteristics</th></tr>
<tr><td colspan="2">Bus compartment dimensions</td><td colspan="2">0.7 x 1.0 x 0.18 m³</td></tr>
<tr><td colspan="2">Payload envelope</td><td colspan="2">0.82 x 0.67 x 0.50 m³</td></tr>
<tr><td>Platform Mass</td><td>149kg / 113kg[1]</td><td>Payload mass</td><td>30kg</td></tr>
<tr><td>Deign lifetime</td><td>2 years</td><td>Thermal control</td><td>Passive, with emergency heaters</td></tr>
<tr><td>Bus power consump-tion</td><td>819W Peak
158W Average</td><td>Payload power consumption</td><td>115W Average</td></tr>
<tr><td>Solar panel capability, sunpoint-ing, EOL</td><td>515 W</td><td>Power generation (design scenario)</td><td>312 W</td></tr>
<tr><td>TM/TC
Uplink
Downlink</td><td>
8 Kbit/s
270 Kbit/s</td><td>Payload data</td><td>27GiB / day</td></tr>
<tr><td>ACS Agility</td><td>Slew [Deg] / Time [sec]
5 / 60
10 / 90
15 / 100
30 / 130</td><td>ACS Stability</td><td>0.875 arcsec / 200ms</td></tr>
</table>

Table 1: Satellite bus main characteristics

[1] : No margins assumed

5.1. Design and development of a new satellite bus

The design and development of the satellite bus for the first DLR-Kompaktsatellit mission is based on the extensive use of “Commercial of the Shelf” (COTS) components. The main development effort has been focused on the core of the satellite bus, namely the avionics and power subsystem. The avionics subsystem for the DLR-Kompaktsatellit bus is a new development based on the experience gained from the BIRD and TET-1 satellite programs. The power electronics architecture is modular, ensuring that the power subsystem can be adapted to future missions without requiring a new detailed design phase.

The internal development of the core system elements ensures that any redesign required for future missions can be performed internally.

5.2. Design Drivers for the satellite bus

The satellite bus for the first DLR-Kompaktsatellit mission has been designed specifically for the AsteroidFinder mission and the requirements from the payload for this mission. The primary design drivers for the satellite bus are summarized below:

High agility between observations: In order to maximize the time available for scientific observations the spacecraft must minimize the time spent in slewing between two inertial pointing attitudes.

High pointing stability during observations: The spacecraft requires high stability during observations in order to prevent blurring of the images taken by the AFI. The pointing stability requirement affects the actuators which can be used for the attitude control system, and therefore is closely related to the high agility requirement.

Payload data generation volume: The payload will generate approximately 27GiB per day with a peak generation rate of 3GiB per hour during the nominal mission. With 4 ground station contacts per day, providing a total contact time per day of ~26 minutes, this requires a relative large amount of onboard storage, and a high speed data link.

Power demand: AsteroidFinder has a relative high power demand for its class. One of the primary contributors to the MoI of the spacecraft is the solar panels, and therefore an optimized panel design, and low power consumption for the satellite is required.

Thermal requirements of the instrument: In order to achieve the required signal to noise ratio in the observations, an operating temperature of -85 degrees C is required at the telescope focal plate. The surrounding electronics all have operating temperatures close to or above 0 degrees C, which results in large temperature differences over relatively short distances.

The following sections will contain a brief description of the systems which constitute the satellite bus. The AFI is presented in more detail in [2].

5.3. Structure and Configuration

The structure of AsteroidFinder is based on a hash(#)-architecture, with two walls extending the full length of the satellite bus (illustrated in red in Figure 6), and the remaining walls being bolted together with the primary walls (illustrated in green). The payload is connected to the bus structure using three quasi-isostatic mounts, of which two are mounted on the intersection between the walls. An additional wall is added to the bus compartment in order to support the last connection point of the payload (illustrated in yellow). The launch adapter is connected to the hash structure at eight points providing a strong and stiff load carrying path from the launcher to the payload. The payload compartment is constructed from carbon fibre struts, which forms the basic frame upon which the MLI and cold radiator is mounted. The structure of the payload compartment and the sunshield can be seen in Figure 6.

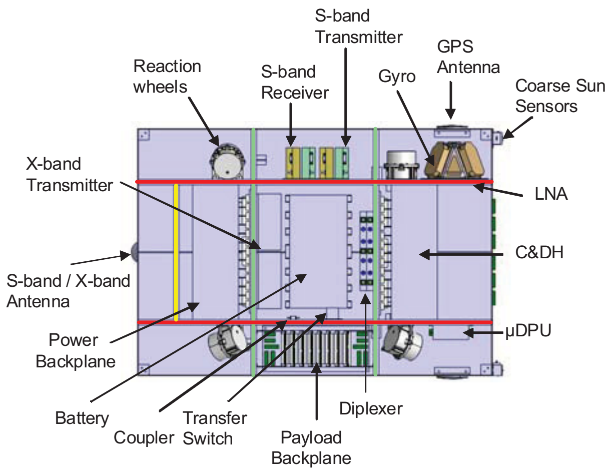

Figure 6: Satellite bus overview

Figure 5: Illustration of payload compartment and sunshield structure

5.4. Avionics System

The core avionics system provides the interconnection of all the units onboard the satellite.

The core avionics consists of: the middleware switch, which serves as a central node of information exchange and data interface for all units onboard the satellite [3]; the onboard computer; and the Analog/Digital units. The X-band transmitters and S-band receivers and transmitters are connected directly to the onboard computers due to high data rates and. TM/TC encoding /decoding ease, respectively. All other connections go via the MWS. An architectural overview of the MWS concept can be seen in Figure 7.

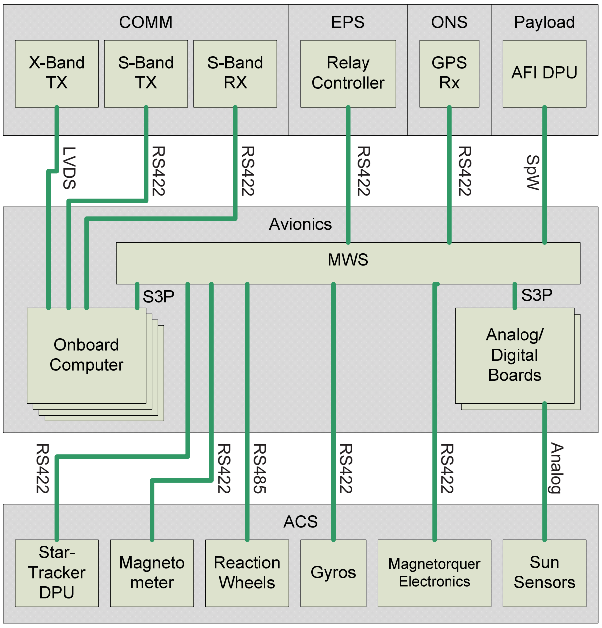

Figure 7: MWS Centered Data Interface Architecture

The MWS is a publish/subscribe multicast bus. Each interface port of the MWS provides a protocol translation layer to enable connection of units with different interfaces and protocols. The MWS is FPGA-based (though possibly later to be implemented in ASIC to increase robustness), and can be tailored to the specific mission and requirements ensuring a quick turn-around time for partial re-use of the satellite bus.

5.5. Electrical Power System

The power system for the AsteroidFinder mission shall deliver 273W on average during the operational phase of the mission to the operating units. The power distribution for AsteroidFinder is based on an unregulated power bus, which is connected directly to the battery. The electrical power system consists of the following elements:

- Solar generator
- Battery charge regulators
- Battery
- Power distribution units
- Power regulation units

The solar arrays consist of 28% efficiency triple junction solar cells, providing a EOL power output of 515W. The cells will be mounted on deployable solar arrays which will be deployed at a 45 degree angle with respect to the telescope boresight vector. This allows for maximum power generation during the operational profile foreseen for AsteroidFinder.

In order to maximize the power output available from the solar panel and to minimize the thermal impact, the battery charge regulation is based on MPPT units rather than a shunt-based approach. Multiple MPPT's are coupled in parallel in order to increase the failure tolerance.

The AsteroidFinder satellite bus is equipped with a 1.2 kWh battery (rated at the beginning of the LEOP phase). The battery design is primarily driven by the requirements for the LEOP phase, and the ability to provide sufficient power for detumbling of the satellite after separation from the launcher without considerable insolation

The power distribution is handled by a controller board which accepts a serial interface, and operates solid-state switches allowing to power units on and off. Depending on the criticality of the unit, various switch combinations are utilized, e.g. for the transmitters a quad-switch configuration is utilized ensuring that a single switch failure does not cause a transmitter fail-on/fail-off scenario.

5.6. Attitude Control

The attitude control system is designed based on the requirements for a high stability during imaging and high agility during slewing. Given that the same actuator configuration is used to control the spacecraft attitude in both modes the resulting performance is a compromise between the two goals. A tradeoff was performed in order to assess the feasibility of using a cold gas propulsion system; however this was disregarded considering the high amount of propellant required for 500-700 daily slews.

Thus the actuator configuration selected is based on the heritage design from BIRD and TET-1 consisting of reaction wheels and magnetorquers. The magnetorquers are used to de-saturate the wheels, as well as to detumble the satellite in the initial phase after separation. With this actuator configuration it is possible to achieve an acceptable performance.

The attitude determination is performed using a combination of gyros, magnetometers, star trackers, and sun sensors. In order to achieve the high pointing accuracy the AFI will be utilized as an additional rate and attitude sensor when fine pointing is required.

5.7. Communication

AsteroidFinder includes two communication systems: TM/TC downlink/uplink in S-Band, and the payload data downlink in X-Band. The two systems operate independently of each other, and will be used simultaneously in the nominal mission scenario.

The TC uplink operates with a bitrate of 8Kbit/s. The TM downlink has a datarate of 270Kbit/s. In the nominal phase of the mission, one TM/TC ground contact is foreseen per day. All TM/TC contacts in the nominal mission scenario are scheduled to be performed by the GSOC via the ground station Weilheim, Germany.

The 27GiB of daily payload data will be downlinked via 4 passes per day at Neustrelitz ground station. This also acts as the Payload Data Center. The required bitrate for the X-band downlink is 138 Mbps.

The communication system provides quasi-omnidirectional coverage in S-Band for both transmission and reception, with the possibility to increase the link margin when transmitting in a nadir pointing attitude by using a dedicated nadir antenna. For the X-band downlink isoflux antennas are used.

6. FUTURE DEVELOPMENTS OF THE DLR-KOMPAKTSATELLIT SATELLITE BUS

The DLR-Kompaktsatellit program is envisaged to support several missions in the future. Therefore the satellite bus for the AsteroidFinder mission has been designed with a vision of modularity and adaptability towards future missions.

As described in Section 5.2 the key design drivers for the AsteroidFinder mission were a high agility between observations and a high stability during observations (data acquisition). If the requirement for high stability is reduced (e.g. for an earth observation satellite) the satellite bus can provide a highly agile platform by increasing the size of the reaction wheels; alternatively the stability can be increased by reducing the size of the reaction wheels, with a lower agility as a consequence (e.g. for an nadir-pointing satellite which does not require fast off- groundtrack observations).

As described in Section 5.6, during Phase B of the platform development the possibility of adding a cold gas propulsion system to provide orbit and attitude control was investigated. While deemed not advantageous for AsteroidFinder, this configuration could also prove useful for an earth observation satellite with requirements for orbit control.

Furthermore, while the payload power provided by the AsteroidFinder platform is already high for a small satellite, given the modularity of the power subsystem the power generation or storage (for eclipse periods or periods of high demand) capabilities can be increased without major impacts on the bus architecture.

It is also possible to reduce the cost of the future mission via tailoring of the bus performance. For instance, the sunshield and payload envelope can be reduced to enable fitting in a piggy-back launch envelope, thus potentially reduing launch cost.

The interfaces between the payload and the bus segment can be adapted in a similar fashion, with RS-422, RS-485, LVDS, MIL-STD-1553 and SpaceWire already supported, and others available with minimal development effort.

7. CONCLUSION

DLR initiated the DLR-Kompaktsatellit program with the objective of establishing end-to-end system competency within DLR for space-based R&D projects. The AsteroidFinder mission shows that the objectives has been fulfilled by allowing a DLR developed payload access to space, and carry out a mission with a high scientific output. This mission, being the first of the series, marks the initial application of the tailored standards and procedures, and thus helps to refine the design process, integration and verification procedures for future missions.

The AsteroidFinder platform is a good example of the utilization of a small satellite platform for a mission with a high scientific return. The performance of the satellite bus developed for the AsteroidFinder mission has been well characterized during the Phase 0, A and B design and is well understood by the engineering team. The satellite bus can be adopted for future mission demands, either in its current configuration or tailored to meet specific needs (e.g. with the addition of orbit control).

8. REFERENCES

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