STEP BY STEP REALIZATION OF AN OPERATIONAL ON ORBIT DETECTION NETWORK

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ABSTRACT

The knowledge of small (>, 100 µm) but abundant objects in space is low. To analyze the quantity of those small objects in Earth orbit is a challenging issue and a number of different methods has been proposed and investigated in the past. However, until today there is no realised solution, which provides sufficient measurement data to be used for software validation. To improve our knowledge regarding the space environment, a new type of in-situ sensor was developed at DLR in Bremen, Germany. The Solar panel based Impact Detector "SOLID" is a large-area impact sensor that can be placed on a spacecraft in any orbit and can provide measurement data continuously. This paper provides an overview regarding the already performed as well as planned development of the SOLID system. Furthermore, the main objectives corresponding the first and second on orbit verification of SOLID on TechnoSat mission (2017) and S²TEP (2019) respectively are outlined.

Keywords: in-situ sensor, SOLID, solar panel based impact detector, space debris detector, on orbit verification

1 INTRODUCTION

The validation of space debris models like ESA´s Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) [1] or NASA´s Orbital Debris Engineering Model (ORDEM) [2] is performed by comparison of simulated results with in-situ measured or orbital observed data. The latter is utilized for large particles and can be obtained from ground based or space based radars or telescopes. Data regarding very small but abundant particles can also be gained by the analysis of retrieved hardware [3], [4]. This has been previously demonstrated, for example with hardware returned from orbit to Earth (e.g. Hubble Space Telescope parts). Furthermore, in-situ impact detectors are an essential source for information on space debris (SD) and micrometeoroids (MM). Such detectors are placed in orbit and collect impact data regarding SD and MM, sending data in near real time via telemetry. Compared to the impact data which is obtained by analysis of retrieved surfaces, the detected data comprises additional information e.g. regarding exact impact time and, depending on the type of detector, on the orbit and particle composition [5], [6]. Nevertheless, existing detectors have limitations. As the detection areas are typically small, statistically meaningful numbers of impacts are only obtained for very small [1], [5] particle sizes. Measurements of particles in the size range of hundreds of microns to mm, which are potentially damaging to spacecraft (S/C), require larger sensor areas. To make use of the advantages of in-situ impact detectors and to increase the amount of collected impact data, an innovative and recently patented impact detector system has been developed at the German Aerospace Center (DLR) in Bremen, Germany [7], [7, 8]. In contrast to previous impact detectors, the Solar panel based Impact Detector (SOLID) is not an add-on component on the S/C. SOLID makes use of existing S/C subsystems and adopts them for impact detection purposes [9], [10]. Since the number of impacts on a target in space depends linearly on the exposed area [11], the S/C solar panels offer an unique opportunity for impact detection. Considering that the SOLID method could be applied to several S/C in different orbits, the spatial coverage in space concerning SD and MM can be significantly increased [9]. In this way the method permits the generation of large impact datasets, which can be used for environmental model validation. The first on orbit demonstration of the SOLID system on the TechnoSat mission as well as planned developments for the second mission S²TEP are discussed in the following.

2 REALIZATION OF OPERATIONAL IS-SITU DETECTION SYSTEM

Considering the lack of available measurement data, the DLR developed an innovative in-situ detection method that makes use of already existing spacecraft subsystems (e.g. Power, ACS) [9], [12]. The sensor system can be easily adapted to the customized satellite solar panel design e.g. on small satellites like CubeSats or large systems like Sentinel [9], [12], [13]. The detection area of the sensor is limited to the solar panel dimensions and the operation time to the designated mission lifetime. The specific mass of the sensor is about 200 g / m² and the power consumption is mainly depends on the selected microcontroller and lies at the range of mW [13].

Since the SOLID sensor can be implemented on different spacecraft and in different orbits the main goal is:

Implementation of the SOLID sensor on a large number of spacecraft for operational use

to provide measurement data e.g. for real time environmental model validation or spacecraft health monitoring. Therefore, we follow a step by step on orbit verification approach as described in the following. After successful approval of the system it shall be possible to provide measurement data from different orbits continuously.

The experimental proof of concept of the idea to use solar panels for impact detection was successfully performed in 2013 at Fraunhofer EMI, Freiburg, Germany [14], [15]. In total, seven Hypervelocity Impact (HVI) tests (HVI) were conducted using projectiles with a diameter between 500 µm and 2 mm [15]. It was shown, that based on available solar panel damage information the impactor diameter can be estimated. In this way the basic principle of the SOLID detection method was clearly demonstrated [12], [15].

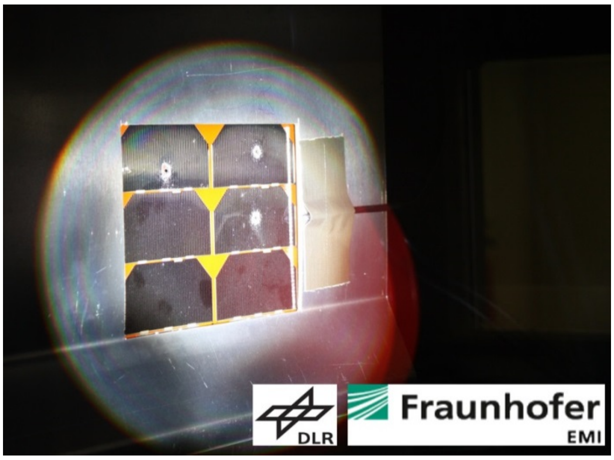

Figure 1. Illuminated SOLID prototype within the Fraunhofer EMI Space Gun target chamber

During the testing, the six solar cells on SOLID prototype were illuminated by the sun simulator that provides a sun equivalent light (see Figure 1). It was shown that an object that hits an illuminated solar cell cause a specific disturbance in the power supply [12]. This disturbance event can be utilized for Time of Impact (ToI) identification [9], [12]. The principal idea of the ToI determination was discussed e.g. in [7], [8], [16]. Furthermore, some considerable theoretical as well as practical work was already conducted by Wartmann [17] and Olsen [18].

After successful HVI testing on ground the next step is On Orbit Verification (OOV) of the SOLID system. The in-situ impact experiment has been already selected for two satellite missions. The first one is the technology demonstration mission TechnoSat of the Technische Universität Berlin which is scheduled for launch in summer 2017. The second one is the S²TEP mission (Small Satellite Technology Experimental Platform) which is an in house project of DLR and scheduled for launch in 2019. On both missions different on orbit verification aspects of the SOLID system shall be addressed. Table 1 shows a summary of information intended to be generated on TechnoSat and S²TEP mission respectively by using SOLID sensor. A short description of the missions as well as the corresponding goals for the SOLID experiments can be found in the following chapters.

Table 1. Generated information on TechnoSat and S²TEP missions using SOLID sensor

Impact Information	TechnoSat	S²TEP
Impact position on solar panel	X	X
Impactor size	X	X
Time of Impact	(X)	X
Impactor velocity	(X)	(X)
Impact direction	(X)	(X)

2.1 SOLID ON TECHOSAT MISSION

TechnoSat is a In Orbit Demonstration (IOD) mission that carries seven different payloads [19]. The TechnoSat spacecraft is based on the modular TUBiX20 platform of Technische Universität Berlin [20], has a launch mass of 20 kg and dimensions of 465 × 465 × 305 mm³. The S/C is designed, manufactured, integrated and tested by Technische Universität Berlin. The TechnoSat mission is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) through the German Aerospace Center (DLR) on the basis of a decision of the German Bundestag (Grant No. 50 RM 1219). Figure 2 shows the flight model of TechnoSat while eing preprepared for thermal vacuum testing at the German Aerospace Center (DLR), Institute of Optical Sensor Systems in Berlin, Germany.

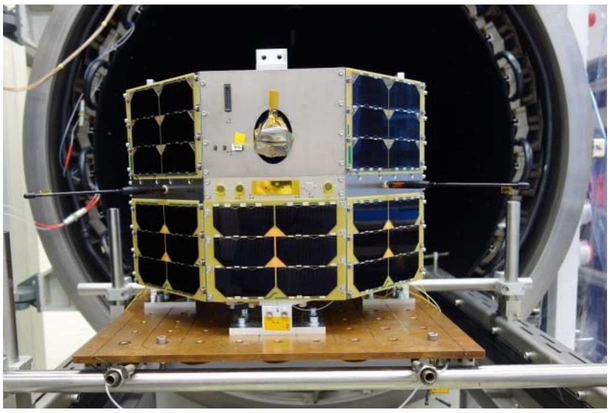

Figure 2. TechnoSat flight model of Technische Universität Berlin during preparations for testing

The main goal of the first on orbit verification is the testing of the solar panels equipped with SOLID sensor. Therefore, a considerable effort was spend for developing and testing of such panels. The satellite is equipped with four impact detection panels which are placed on four sides of the satellite as shown in Figure 3. One solar panel has a detection area of about 200 cm².

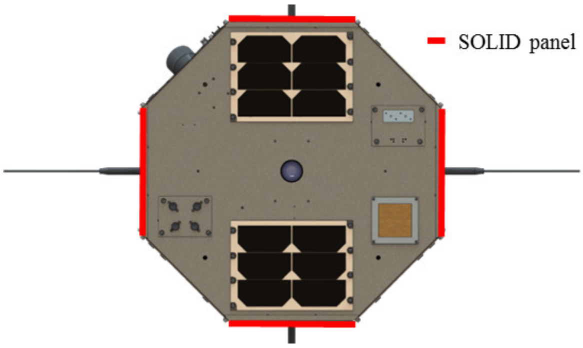

Figure 3. Arrangement of SOLID sensors on TechnoSat as seen from the S/C's side directed towards nadir [21]

Figure 4 shows the SOLID equipped solar panel manufactured for the TechnoSat mission. The X and Y traces behind the solar cells are indicated on the enlarged view. In case of an impact event those traces will be severed and can be identified as such by a dedicated electronics. Based on number of severed traces the damage in X and Y direction can be estimated. Using ESA damage equations [4] and the damage size information from the solar panel the impactor diameter can be estimated [12], [15].

The four detection panels at the TechnoSat mission will be scanned sequentially one after another. This means, that the knowledge regarding *time of impact* (ToI) is limited to the analysis process. However, the time interval in default configuration is small enough to meet the ESA MASTER requirement. Furthermore, on the TechnoSat mission this parameter can be altered if required. The exact knowledge of the ToI is however important and will improve our knowledge regarding the space debris and micrometeoroids environment. Therefore, improved ToI information will be provided by the SOLID sensor implemented on the S²TEP mission in 2019.

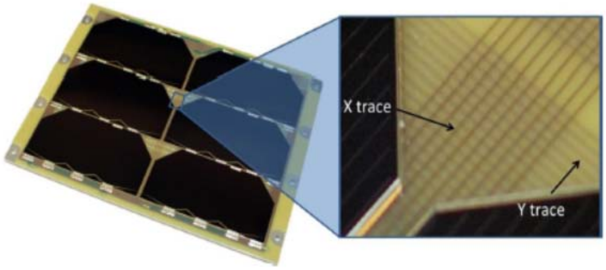

Figure 4. TechnoSat solar panel equipped with SOLID sensor [21]

The velocity of the impactor on the TechnoSat mission will be derived from the MASTER model. Furthermore, the housekeeping data of TechnoSat will be analysed regarding accruing anomalies (change of S/C's rotation rate) after an impact. Based on this information a rough estimation of the momentum transfer to the satellite shall be performed. However, since the sampling rate of housekeeping data is in the range of seconds, it is a matter of luck if we will even see any impact induced disturbances. Nevertheless, we will exploit this additional source of information to gain lessons learned for upcoming missions. The determination of impact direction at the TechnoSat mission is limited to the knowledge regarding the orientation of the solar panels at the time of impact.

2.2 SOLID ON S²TEP-MISSION

The Small Satellite Technology Experimental Platform (S2TEP) is a scalable bus within the microsatellite class (10-100 kg), currently under development at DLR [22]. It shall allow an accommodation of a variety of small scientific payloads with a mass of up to 10 kg and a power up to 60 W [22]. The future S²TEP-based missions are characterized by short development times due to a technology-driven design approach of DLR [22]. Instead of customizing every satellite to a specific instrument the S²TEP platform shall provide dedicated and partly adaptive interfaces. In this way an accommodation of different payloads shall be possible.

Although the platform will make use of many commercial-of-the-shell components (COTS), the core avionics elements are based on DLR in-house technologies which will be integrated as demonstration payloads for the first S²TEP reference mission. The reference mission is designed for a launch mass of ca. 50 kg with an overall envelope of up to 60 x 60 x 80 cm^3 [22]. Figure 5 shows a preliminary CAD model with the three key segments of the scalable S²TEP platform:

- Bus compartment with avionics box
- Payload compartment on top of bus compartment and under S2TEP adaptable hood
- Launch adapter interface plate

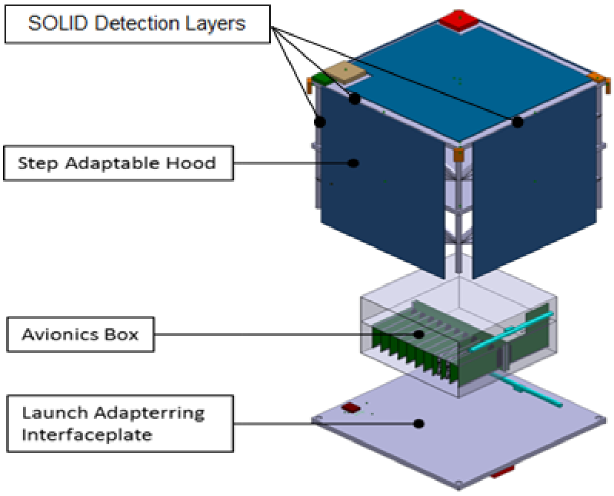

Figure 5. S²TEP preliminary configuration [22]

In current configuration, the S²TEP satellite has five body-mounted solar panels with an array area of 0.15 m^2 each, which shall be used for the second OOV of the SOLID impact detector. Depending on the power demand of future missions the S²TEP satellite can also be equipped with deployable solar panels. The platform development is a DLR in-house activity. The main aim of the project is to launch every 2-3 years a satellite into space and to test new payload as well as bus technologies. Therefore, the S²TEP project is of great interest for the further SOLID developments, since it offers possibility to test new features and to optimize the system for future operational implementation on different satellites.

The main goal of the second OOV of SOLID is the development and testing of the Time of Impact (ToI) functionality. For an autonomous impact identification system a processing unit comprising a dedicated electronics and corresponding software is required. The basic idea here is to perform an analysis of the solar array current / voltage disturbances. This event shall be utilized as a possible impact event. After identification of such event the affected panel will be analyzed regarding the presents of damage on it. In this way more precise ToI information can be matched to the occurred impact. The already developed scan function for the TechnoSat mission will be also included to the analysis process. Since small impacting objects may produce small disturbances in the power system only those impact will potentially not be detected. However, the same object may generate considerable damage on the solar panel.

For the S²TEP satellite solar panels it is anticipated to use a sandwich substrate made of aluminum honeycomb with carbon-fiber re-enforced plastic (CFRP) cover sheets. The HVI ground testing of SOLID prototype was performed with EuReCa comparable solar panel design as shown in Figure 6. More detailed design information can be found e.g. in [9], [10], [12]. Special attention was paid to comparability of the SOLID prototype panel to the HST and EuReCa solar panels. This allows a direct comparison of damages generated on SOLID panel with those available from HST and EuReCa solar panels.

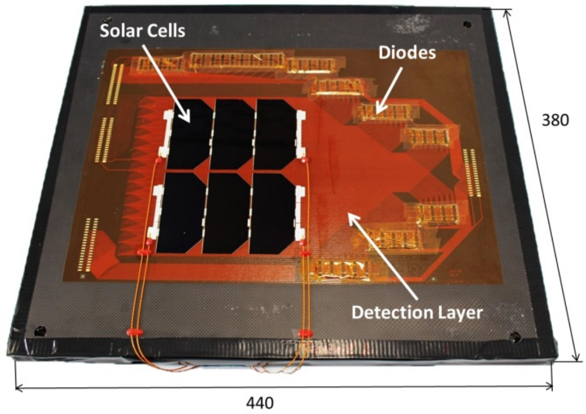

Figure 6. Setup of SOLID solar panel for HVI testing [12]

The ground testing set up was sufficient for method verification. However, for an on orbit verification, additional research work will be required. Therefore, an additional goal for the second OOV is the definition and application of the manufacturing process. Special attention will be paid to the application of the detection layer to the CFRP / aluminum substrate for example. Because of different thermal expansion coefficient suitable glue system needs to be selected and tested under real conditions. Different adhesives and adhesive tapes (such as e.g. NuSil® silicon adhesives), gluing the SOLID detection layer to a panel structure will be applied and tested. The most promising glue system(s) will undergo additional HVI tests in order to identify potential deviations in the impact damage layout compared to the initial ground testing. Furthermore, a compact routing concept in-between the electronics box and the SOLID panel needs to be developed and manufacturing procedure aspects need to be analyzed and adapted.

In summary, the SOLID further development for the S^{2}TEP mission in 2019 aims for the following:

- Implementation of a Time of Impact functionality into the SOLID electronics to process S/C housekeeping data for dedicated detection layer analyses,
- identification and application of a modular detection layer to panel substrate bonding concept,
- design of a compact but flexible routing concept of the detection lines to reduce harness and enable easy integration and adaptation of the S/C subsystems and SOLID elements.

3 SOLID Implementation to Large S/C

The long term goal of the SOLID system is the implementation of it on different spacecraft and in different orbits. Therefore, also the currently in use ISS is an interesting test bed for long-term technology demonstration and for continuous operational orbital debris detection. An advantage of the utilization on the ISS is that this orbital debris detector could be retrieved to the Earth after long-term in orbit operation. This permits laboratory investigations regarding the quantity of registered detector impacts and analysis of material degradation. The solar cells demonstrators which are replaced from time to time on the ISS could be equipped with SOLID sensor for example. Those demonstrators could be installed at the exposed facilities on the ISS as shown in Figure 7.

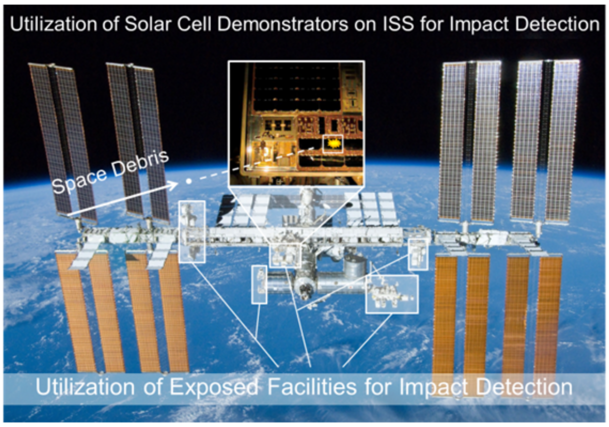

Figure 7. Utilization of exposed ISS facilities for impact detection [23]

Figure 8 shows damages on the 3A solar panels of the ISS. A 7-mm-sized perforation on the panel broke a bypass diode and caused overheating of the array and lead to a total failure of a string with 400 cells [24].

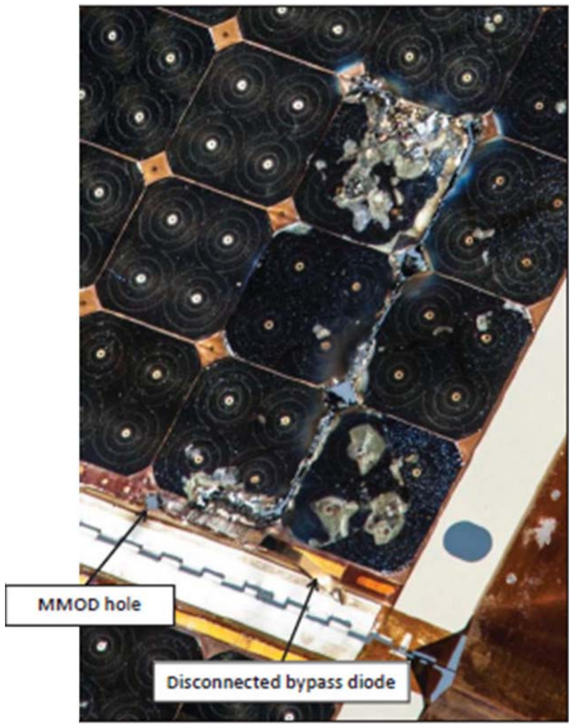

Figure 8. ISS Solar Array 3A damage [24]

The upcoming space station, which is currently also under investigation e.g. at DLR, NASA, ROSCOSMOS, JAXA, offers also unique possibility for implementation of SOLID. In this Post-ISS vision the solar panels could be equipped with SOLID sensor. The sensor could help to gather real time status of the panels without an extra-vehicular activity (EVA) of the astronauts becomes necessary for inspection.

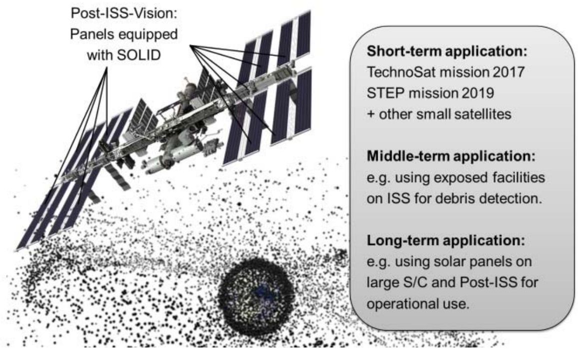

Figure 9. Solar panels equipped with SOLID sensor for in-situ detection, Post-ISS vision [23]

4 CONCLUSION AND OUTLOOK

To gather information regarding small (< 1 cm) space debris and micrometeoroids the DLR has developed an innovative in-situ detection method SOLID. The method was successfully verified on ground by HVI testing. The first on orbit verification of SOLID will be performed on the TechnoSat mission which will be launched into orbit in summer 2017. The main goal of the first mission is the testing of the SOLID solar panels in orbit. The second mission S²TEP is scheduled for launch 2019. Here the Time of Impact functionality shall be developed and tested. The measured orbital debris and micrometeoroid data can be used to complement the Space Surveillance Network (SSN) catalog data and to close the gap where only little data exists. A data gap exists between ground based measurements and measurements gained from retrieved hardware e.g. Long Duration Exposure Facility (LDEF), Hubble Space Telescope (HST), European Retrievable Carrier (EURECA). Furthermore the data can be used for environmental models validation, risk assessment for critical space assets and also for space-based systems optimization.

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