THE VULNERABILITY ASSESSMENT AND DEBRIS PRODUCTION RISK MITIGATION IN COSMO-SkyMed CURRENT AND FUTURE GENERATIONS

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ABSTRACT

Every spacecraft in Earth orbit is exposed to a certain flux of micrometeoroids and man-made space debris. Because of large collision velocities, MMOD may damage the spacecraft, depending on the size and the direction of the impacting particle and on the characteristics of the impacted item, in some cases the damage can be catastrophic.

The design of Spacecraft can on one side prevent generation of debris, controlling the dimension of released particles and retaining detached objects, and on the other side can be shielded in order to resist to impacting hypervelocity objects.

For the COSMO-SkyMed Satellite Constellation, an Italian Space Agency and Ministry of Defense Programme, developed by Thales Alenia Space Italy as Large System Integrator, the Satellites have been designed by implementing rules for debris mitigation by implementation of collision manoeuvres, Satellites shielding etc.

With the Second Generation of the Programme COSMO-SkyMed Second Generation, updated analytical tools for recurrent design validation have been implemented aimed at detailed analysis including internal items modelling.

For the next generations further improvements aimed at minimising the risk of fragmentation and particles release are being identified and a preliminary ranking is under evaluation together with associated feasibility of implementation in the near-to-far generations. In particular, the paper will focus on the control of energy sources at end of life in order to minimise the internal causes for rupture and fragmentation.

1 Introduction

Micrometeoroids and man-made Space Debris jeopardise Spacecraft Missions Safety and consequently Safety of the Orbital Belts around the Earth.

Spacecraft are at the same time a potential source of Space Debris Flux and it is vulnerable to it.

This double perspective induced two typology of analyses and intervention at Spacecraft level for Debris Mitigation.

For COSMO-SkyMed different design and operational strategies have been put in place at Design and Operational Level for the minimisation of the Risk of Satellites fragmentation due to External Sources.

2 Strategies for the Minimisation of Spacecraft Fragmentation Risk due to Space MMOD

The population of Micrometeoroids and Debris Threatening objects can be categorised depending on the size of the particles, due to the different effect on the Satellite following to impact.

Meteoroids are in orbit around the sun while debris are man-made artificial objects such as non-functional spacecraft, abandoned launch vehicle stage and fragmentations products. These particles can collide at very high velocity causing damages either on the spacecraft systems or even induce mission failure due to catastrophic collision. The highest risk to space mission comes from the particles that the NORAD Space Surveillance Network is not able to track, which limit diameters is around 10 cm.

Shields can be effective in withstanding impacts of particles smaller than 1 cm. While discrete objects smaller than 10 cm and larger than 1 cm are usually too small to track and too large to shield against, therefore they represent a critical issue for the S/C.

Moreover objects with dimensions higher than 10 cm cause catastrophic events by not only losing the

Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office
Ed. T. Flohrer & F. Schmitz, (http://spacedebris2017.sdo.esoc.esa.int, June 2017)

Spacecraft control, but also generating a cloud of debris with high risk for all the surrounding Satellites.

Therefore for trackable object a manoeuvring strategy for collision avoidance is typically forseen as soon as the Space Surveillance Network rises a “collision alert”.

In this case the “time to collision” is the most important parameter to size the:

- On-board propellant
- Thrusters selection
- manoeuvre strategy

In fact according to the probability of occurrence of such conjunction with NORAD traced objects in the COSMO-SkyMed Orbits, the number of manoeuvres per year, the dedicated quantity of propellant and manoeuvre strategy has been defined since the first Constellation.

At analysis level the probability of catastrophic collision with large debris has been evaluated for COSMO-SkyMed Satellites with both the ESABASE2/Debris (with MASTER2009 debris environment) and the MASTER2009 software tools.

In case of object dimensions below 10 cm , there is no possibility, up to date, to track them and to operate a manoeuvre strategy for collision avoidance.

In this case dedicated Design adaptations can be foreseen to cope with potential impacts due to Micro-Meteoroids and Orbital Debris

One of the major interventions at design level regards the Platform Skins Thickness and Equipment internal configuration.

Analyses performed to assess the potential risk induced by Micro-Meteoroids and Orbital Debris to the external structure and external items of the COSMO SkyMed Satellites, drove the definition of Structure Skins thickness.

Analyses performed with ESABASE tool since the first generation of CSK, evolved to ESABASE2 tools and from ORDEM96 to MASTER 2009 debris population models, but the major improvement is implemented in specific routines for the modelisation of internal SC items and the effects of impact-penetration of particles on them, along with their failure weighting by implementation of a Fault Tree.

The analysis performed for COSMO-SkyMed Second Generation addresses the probability of the SC to collide with medium size particles (between 1 cm to 10 cm) that could damage the SC without leading to the loss of the mission, with the aim to evaluate the skin thickness apt for platform external panels and assess Probability Of No Perforation and Probability of no Failure of the internal items shielded by structural panels .

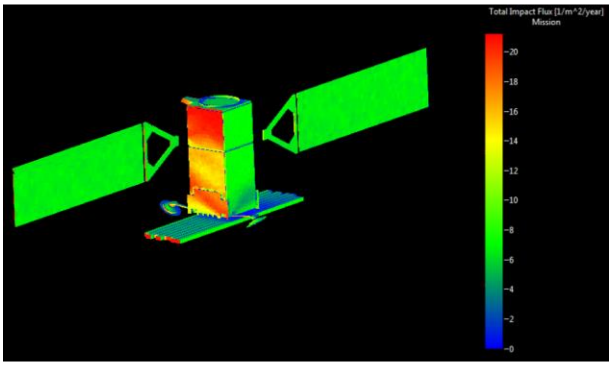

Figure 1. Total Impact Flux on CSG External Structure (+X Side).

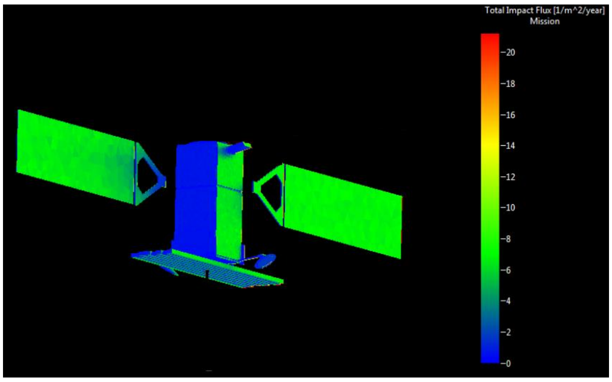

Figure 2. Total Impact Flux on CSG External Structure (-X Side).

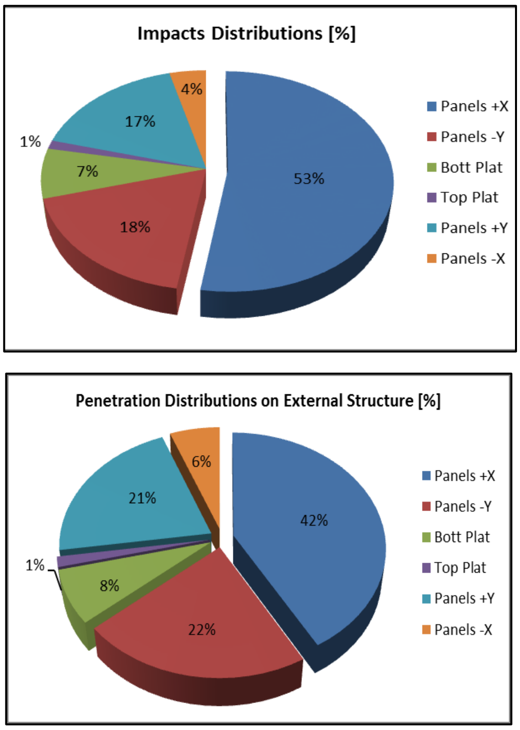

Figure 3. Impacts Distribution and Perforation Distribution on the CSG External Structure

To take into account the probability that an impact on the spacecraft structure wall, could damage internal equipment located inside the bus, a detailed impact assessment was performed.

In the frame of this analysis the internal equipment vulnerabilities due to debris and micro-meteoroids particles impacts have been studied.

The first analyses performed for CSG exploited a study funded by ESA and dealing with "Vulnerability of Spacecraft Equipment to Space Debris and Meteoroid Impacts" (RD2) that presented an approach to quantify equipment vulnerability. This approach considered the intrinsic protection capabilities of S/C internal equipment, and the specific failure probability of internal components.

The experimental data collected during this study showed that a perforation of the equipment cover wall does not necessarily lead to loss of the equipment placed behind it. For electronic boxes (e-boxes), the failure mode "permanent failure" was defined as permanent malfunction of vital elements of the e-box or complete destruction of the e-box with no operational capabilities left after the impact. Using this approach and considering as a "failure" the "permanent failure" of electronic equipment located underneath the sandwich external panels, the "the probability of failure" given a perforation can be deduced and related to the ratio between the critical diameter obtained by the BLE and the actual diameter of the impacting particle.

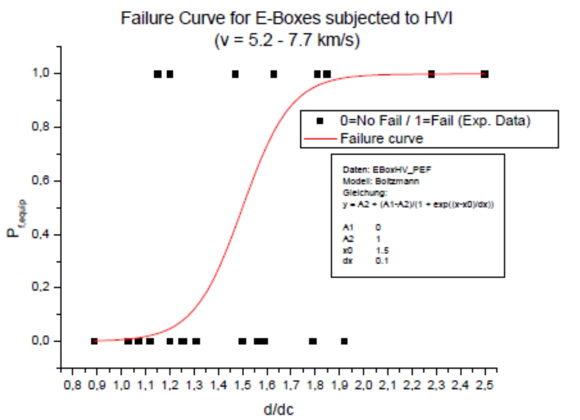

Figure 4. Failure curves of e-boxes subjected to impact in the velocity range of 5.2 – 7.7 km/s as function of d/dc

This approximated approach has been then substituted by a detailed analysis including dedicated subroutines to ESABASE2 tool for modelling the behaviour of the internal items to impacts of MMOD.

The spacecraft items both external and internal, have been modelled configuring their shielding properties through the proper BLE. Both double and multiple walls models have been used to simulate the items structural response (i.e. BLE Schäfer-Ryan-Lambert triple wall model used).

At the same time a detailed model of the Spacecraft has been built in ESABASE2 in order to allow the tool to consider impacts and penetrations for each of the internal equipment boxes.

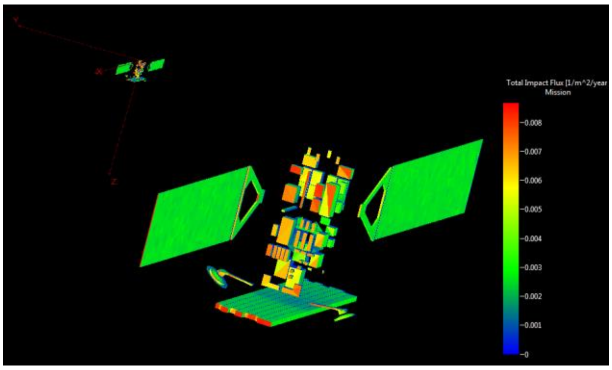

Figure 5. Total Impact Flux Distribution on the Spacecraft Internal Elements (+X Side).

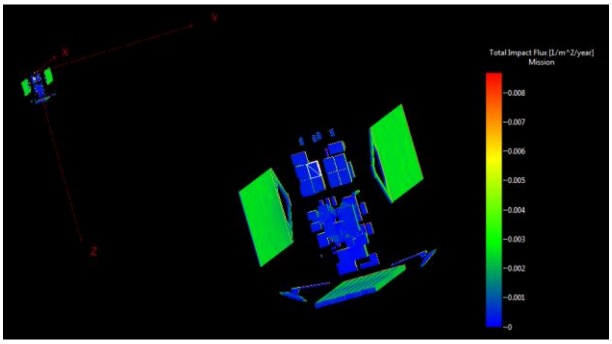

Figure 6. Total Impact Flux Distribution on the Spacecraft Internal Elements (-X Side).

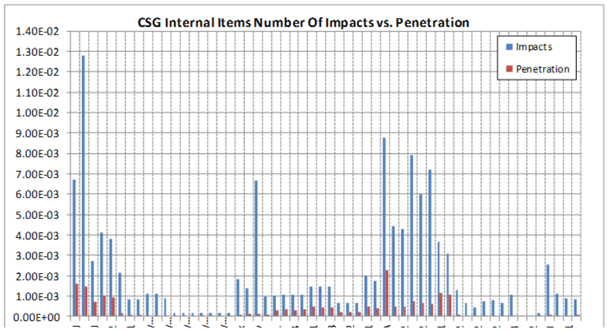

Figure 7. Histogram of the CSG Internal Equipment Number of Penetrations vs Number of Impacts.

In addition to this the most conservative assumption initially adopted was that any single component failure would produce its complete functional unavailability.

In this case the components/equipments probability of failure are simply summed to obtain the overall system probability of failure.

Then a Boolean logic has been used for S/C architecture model to assess the system level effects resulting from the loss of individual S/C equipment due to MMOD impact.

The S/C Fault Tree scheme has been defined and the final risk is based on the introduced Boolean logic operation. The risk of failure is mitigated by taking into account the existing redundancies and the minimum critical number of items that guarantee system functions.

In this case, the overall system failure probability is mitigated multiplying the redundant items. Each equipment has been classified in terms of equipment type and redundancy. Based on this consideration the items have been classified either “critical” or “not critical”. Critical items are those internally redundant, while “not critical” items are those with a stand-by-spare.

Equipment “failure correction factors” and the SC fault tree damage scheme have been considered to determine the number of failures that could determine either the loss of the item functionality or complete subsystem failure.

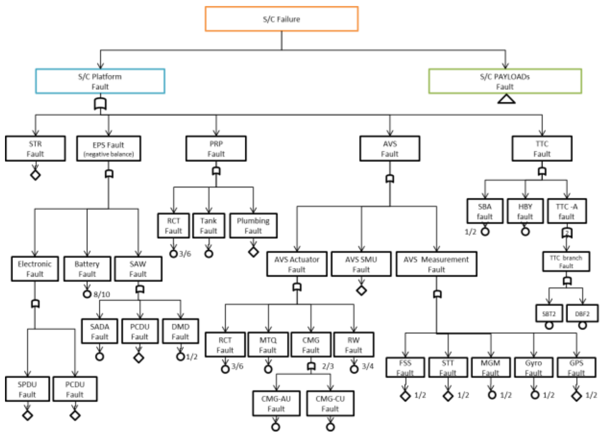

Figure 8. FT for CSG

3 ABBREVIATIONS AND ACRONYMS

CSK	COSMO-SkyMed
CSG	COSMO-SkyMed Second Generation
TASI	Thales Alenia Space Italy
SC	Spacecraft
S/S	Sub-System
AOCS	Attitude and Orbit Control Sub-System
FMEA	Failure Mode Effects Analysis
PNI	Probability Of No Impact
PNP	Probability Of No Perforation
PNF	Probability Of No Failure
LEO	Low Earth Orbit
EOM	End of Mission
EOL	End of Life
SAW	Solar Array Wings
PLM	Platform Module
MMOD	Micro-Meteoroids and Orbital Debris
BLE	Ballistic Limit Equation
SRL	Schäfer-Ryan-Lambert
FT	Fault Tree
PCDU	Power Conversion and Distribution Unit

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