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FAST AND FLEXIBLE SPACE DEBRIS RISK ASSESSMENT FOR SATELLITES

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ABSTRACT

The rapid increase in uncontrolled high velocity objects orbiting earth poses a continuously growing failure potential for ongoing and future space missions. Despite increasing efforts to mitigate collisional risks, e.g. via active debris removal, potential solutions are currently only emerging at the horizon, emphasizing the importance of space debris related risk assessment.
However, traditional impact shielding requirements for manned mission cannot directly be transferred to unmanned missions. Instead of restricting the analysis to the outer hull, it is necessary to directly assess the failure risk on the level of individual, internal components.
Here, we outline a newly developed deterministic methodology to enable the evaluation of system level effects on the spacecraft. In particular, we employ a computational model based on available probabilistic debris models and component-specific ballistic limit equations. The methodology has been implemented into the easily accessible software tool PIRAT (Particle Impact Risk and Vulnerability Assessment Tool).

1. INTRODUCTION

The continuing accumulation of space debris in heavily used orbits such as the LEO presents an increasing threat for civil and military satellite infrastructure [1-2]. Until effective debris removal strategies are designed and set into motion, space missions will have to rely on a combination of collision avoidance maneuvers for large, traceable objects and damage mitigation by appropriate shielding of the spacecraft for smaller, untraceable debris [3].
Several computational tools, including NASA's BUMPER-II and ESA's ESABASE2/Debris have been developed to assess the risk of mission failure caused by impacts of high-velocity micrometeoroids and manmade space debris [4-5]. Traditionally, the assessment is based on the probability of no penetration (PNP) of the outer pressure wall of the spacecraft [6, 5]. While this approach is well suited for the manned space missions it has been originally developed for, its application to unmanned satellites results in often unnecessary steep requirements stemming from unjustified high failure probabilities. Furthermore, for the majority of unmanned missions, a thorough risk assessment is out of the question due to the connected prohibitive costs.
Here, we present a newly developed software tool, PIRAT, which has been specifically designed for the risk assessment of unmanned missions. It provides an intuitive, reliable, fast, thorough, and resource-effective analysis of a spacecraft for a given set of mission parameters. In particular, we improve on the traditional risk assessment methods by looking beyond structural penetration and additionally investigate impact effects at the level of internal components [7].
The approach is in large parts based on the Schäfer-Ryan-Lambert (SRL) ballistic limit equations (BLE), which is capable of making damage predictions for objects behind multi-plate structure walls such as Whipple shields [8].
In combination with knowledge about the functional architecture of the spacecraft, this allows for a detailed component-level, functionality-based failure analysis.
Furthermore, PIRAT is continually developed, maintained, and tested against available models following the guidelines of the Inter-Agency Space Debris Coordination Committee (IADC) [9]. The performance-oriented approach of PIRAT delivers results within minutes, making it an ideal tool for in-session support, e.g. during the early design phase of European and American space missions [6,10].

2. METHODOLOGY

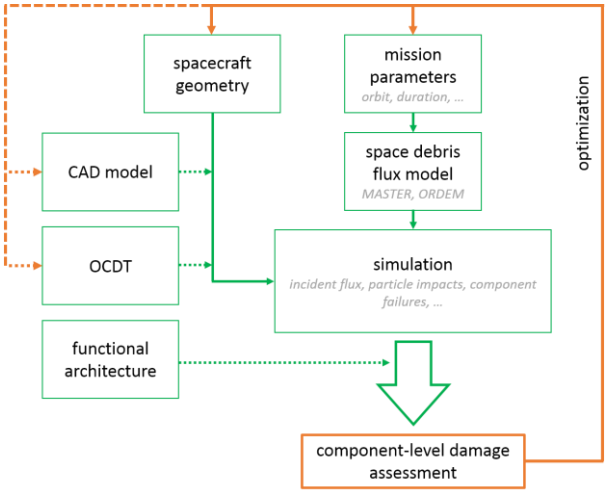


Figure 1: PIRAT operation scheme. 3D geometry and space debris flux data (green) for given mission parameters provided to compute component-level damage on spacecraft. Output (orange) fed back into refinement loop for optimization.

The PIRAT methodology is schematically depicted in Fig. 1 (for a detailed description, see [6, 10]): it requires a 3D satellite geometry as well as space debris flux data

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for a given set of mission parameters. PIRAT combines this

data to compute and display impact-related information, including the total impact flux, the cratering area, as well as the failure probability for every component integrated over the mission duration. The results can be used, e.g., in conjunction with knowledge about the functional architecture of the vessel, to systematically modify the satellite geometry as well as the mission parameters. This optimization loop is repeated until the overall mission supports a sufficiently small failure probability [10].

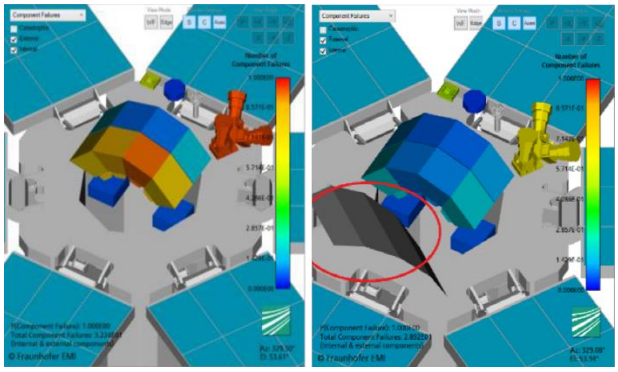


Figure 2: Exemplary component vulnerability reduction by addition of a sun shield (red circle) to the spacecraft geometry. Image adapted from [10].

Catastrophic failure is modelled via energy coupling coefficients of each component and is based on a predefined energy-to-mass ratio. Fig. 2 depicts an exemplary optimization of the failure probability for several satellite components via a slight modification of the spacecraft geometry. The graphical user interface (GUI) is illustrated in Fig. 3.

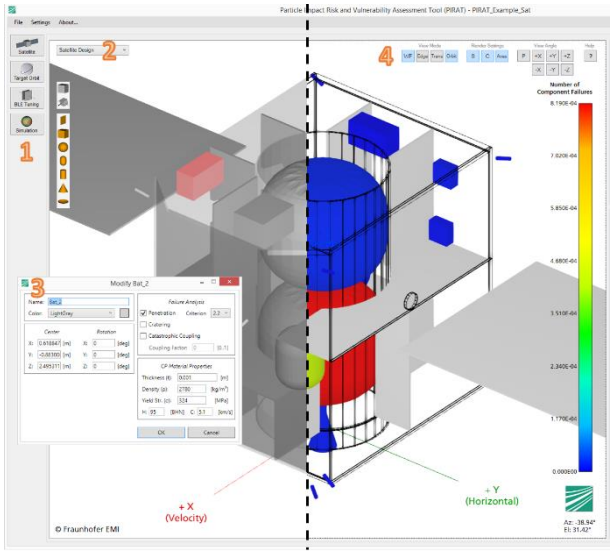


Figure 3: PIRAT GUI in visualization mode. Left half: geometry and material editing view. Right half: results visualization. Numbers: (1) Main menu, (2) viewing mode selection, (3) component material editor, (4) viewport options.

PIRAT provides an interface to ESA's MASTER and NASA's ORDEM space debris models up to the most recent versions, allowing to assess American as well as European missions [11-12].

Internally, PIRAT uses a deterministic approach based on multi-wall BLEs, in particular the SRL BLE [8], to account for failures of internal as well as external components. The SRL is a three-wall equation, which inherently considers failure mechanisms of different component types, including pressure vessels, electronic boxes, cable harnesses, and batteries. It supports opaque impacts, different shielding materials as well as configurations and is founded on a large and continuously growing experimental basis.

The SRL requires a set of material as well as geometrical parameters. Geometrical information is directly derived from the 3D satellite model, which can be constructed within PIRAT using geometric primitives. However, in order to provide greater design flexibility and tap the full potential of current computer-aided design (CAD) software, PIRAT supports direct model import via the Standard for the Exchange of Product model data (STEP) format. Hence, previously constructed models can be directly evaluated within the computational framework of PIRAT.

Material properties, such as physical density or hardness, can also be individually entered in PIRAT for every component and structure. Additionally, PIRAT provides an interface to existing models and parameter sets via ESA's concurrent design facility (CDF). This interface allows to import necessary design as well as mission characteristics via ESA's new mission data sharing system, Open Concurrent Design Tool (OCDT).

3. CONCLUSION

Until effective measures are taken to mitigate collisional risks, impact shielding against untraceable space debris will stay indispensable for spacecraft. While traditional risk assessment is well suited for manned missions, unmanned missions exhibit inherently different requirements. However, prohibitive costs and limited time do often not allow for thorough risk assessment. Here, we provide a flexible, performance-oriented methodology particularly designed for the risk assessment of unmanned missions in the early design phase. With support for CAD geometry data and different space debris models, interfaces to ESA's CDF as well as component level threat evaluation, PIRAT provides the opportunity to quickly perform optimizations on the geometrical model and mission layout. We believe that our methodology will substantially facilitate early mission design by providing a fast, easy-to-use, and resource effective way for satellite optimization.

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