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ScienceDirect

Procedia Engineering 204 (2017) 437–444

Procedia Engineering

www.elsevier.com/locate/procedia

14th Hypervelocity Impact Symposium 2017, HVIS2017, 24-28 April 2017, Canterbury, Kent, UK

Challenges of Debris-Impact Risk Assessment for Robotic Spacecraft

James Chinn[a,*], Martin Ratliff[a]

[a]*Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA*

Abstract

This paper describes an orbital debris impact risk assessment performed on the command and data subsystem electronics box of QuikSCAT, a functioning spacecraft with approximately 18 years on orbit. Several aspects of the analysis are paid particular attention. First is the modeling of a thermal blanket at a small stand-off distance from the box chassis. The properties of the blanket are such that under some assumptions, it may be treated as an effective bumper shield, and under other assumptions, it may not. The assumptions and their effects on the results of the analysis are explored. Similarly, the configuration of the electronic components inside the chassis are such that several definitions of failure criteria appear plausible. The results of each treatment are presented together and compared with the status of the actual electronics box. The failure predictions vary widely between treatments, and the more conservative assumption sets predict incredulously high probabilities of failure. This is problematic because the conservative assumptions are the ones typically used in analyses for flight projects.

Peer-review under responsibility of the scientific committee of the 14th Hypervelocity Impact Symposium 2017.

Keywords: Orbital Debris; MMOD; risk; assessment; Bumper; ORDEM; QuikSCAT

* Corresponding author. Tel.: +1-818-354-9459; fax: +1-818-393-4699.
E-mail address: James.Z.Chinn@jpl.nasa.gov

1877-7058
Peer-review under responsibility of the scientific committee of the 14th Hypervelocity Impact Symposium 2017.
10.1016/j.proeng.2017.09.738

1. Introduction

The design of an Earth-orbiting spacecraft typically addresses the risk of sustaining critical damage from orbital debris. Several tools and damage predictor equations are available to calculate this risk for common configurations. However, shield geometries are frequently encountered that do not fit the characteristics of the data set from which the tools were derived. This adds uncertainty to the analyses, which one is tempted to bound using conservative assumptions. As will be shown in this paper and as often encountered by the authors, bounding the uncertainty in the analysis can lead to an impractically large range of failure probabilities, and conservative assumptions often lead to incredulously high probabilities of failure. To make these analyses more useful, new data sets or new methods of applying the current data sets with more confidence to a wider range of common configurations is desirable. Of particular interest to the authors in their work on robotic missions at JPL are methods of handling Multi-Layer Insulation (MLI) as a bumper shield, of interpreting damage to electronics behind a double wall configuration, and of predicting shield response to steel and copper projectiles.

To illustrate the problem, an analysis of a spacecraft electronics box is presented in this paper. The spacecraft is QuikSCAT, which has been in orbit for approximately 18 years, and the subject electronics box is known to still be fully operational. The effects of several assumptions are investigated. First, the effect of assuming that MLI functions as the first wall, or bumper shield, of a double-wall shield configuration is explored, demonstrating the difficulties of modifying Ballistic Limit Equations (BLEs) to handle marginal shields. Second, the effect of discounting some of the box perforations based on the configuration of the circuit board inside the box is explored. The most conservative treatments predict an extremely high probability of failure, which is difficult to believe given the electronics' functional status. The most optimistic treatment predicts a believable probability of failure. The correct probability of failure ostensibly lies somewhere between the two numbers, but where is uncertain. This is problematic because the difference between the conclusions of the two treatments is so large that it is difficult to say with confidence anything useful about the probability of survival of the electronics box. This problem is not unique to the subject analysis; it is frequently encountered by the authors during their analyses of JPL spacecraft.

2. QuikSCAT Spacecraft

The intent of the analysis was to compare the actual status of a piece of flight hardware to the prediction of the hardware's survival in the debris environment. The spacecraft chosen for this analysis was QuikSCAT (Figure 1). QuikSCAT is an Earth observation satellite whose primary mission was to measure surface wind speed and direction over global oceans using JPL's SeaWinds instrument. QuikSCAT was manufactured by Ball Aerospace & Technologies, and launched in 1999. The science instrument failed in 2009, but the engineering subsystems are currently still functional. QuikSCAT mission parameters are shown in Table 1.

The most appealing aspect of QuikSCAT from an analyst's perspective is the presence of electronics boxes that are directly exposed to orbital debris. This allows for relatively straightforward orbital debris damage analysis.


Figure 1. Artist Depiction of QuikSCAT [1]

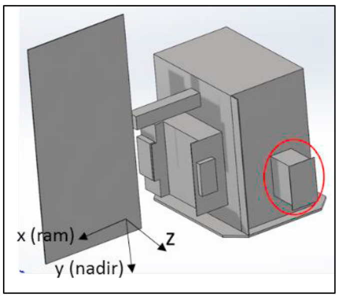

Figure 2. CAD Model of QuikSCAT. CDS Circled in Red.

Table 1. QuikSCAT Mission Parameters

Parameter	Value
Launch Date	June 19, 1999
Perigee (km)	802.5
Apogee (km)	803.9
Inclination (deg)	98.6
Orbit Type	Sun-Synchronous
Target	Earth
Primary Instrument	SeaWinds (JPL)
Manufacturer	Ball Aerospace
Primary Mission Length	10 years, 4 months
Secondary Mission Length	Ongoing