Paper ID: 3764
student

SPACE SYSTEMS SYMPOSIUM (D1)
System Engineering Tools, Processes & Training (I) (3)

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STATISTICAL RELIABILITY ANALYSIS OF SATELLITES BY MASS CATEGORY: DOES SPACECRAFT SIZE MATTER?

Abstract

Reliability has long been recognized as a critical attribute for space systems, and potential causes of on-orbit failures are carefully sought for identification and elimination through various types of testing prior to launch. From a statistical or actuarial perspective, several parameters or characteristics of the design can affect the probability of failure of satellites. For example, the spacecraft complexity and the number of instruments on-board or its payload size, to name a few, have some implications on satellite reliability. In statistical terms, such parameters may be termed covariates for the statistical analysis of satellite reliability, that is, the failure behavior of satellites is correlated with these parameters. One likely covariate of satellite reliability is the satellite mass since mass is a good proxy for spacecraft size and complexity. Several questions follow this observation: for example, are different spacecraft masses correlated with different failure behaviors on-orbit? Do small satellites exhibit different failure behaviors on-orbit, hence different reliability profiles, than larger one? And more broadly, do different satellite classes (in terms of size / mass) have different reliability profiles? Careful statistical analyses are required to address these questions and quantify the correlation, if any, between satellite mass and satellite reliability.

In this paper, we conduct statistical analysis of satellite reliability with mass as a covariate. Our analysis is based on a data set of 1,584 Earth-orbiting satellites successfully launched between January 1990 and October 2008. We first categorize these satellites into four size / mass bins commonly used in the space industry (for example, satellites with mass below 500 kg are commonly referred to as "small sat" and are categorized as such in this work). We then conduct a nonparametric analysis of satellite reliability for each class, using the Kaplan-Meier estimator (given the censored nature of the data). A comparative analysis of failure behavior over time clearly identifies different failure behaviors and reliability profiles for different satellite size / mass bins. For example, our analyses reveal important differences with respect to infant mortality and aging or wear-out between the different classes of spacecraft. Finally, beyond the statistical identifications of these differences, we discuss possible structural reasons for these trends, and conclude with the implications of our findings for the space industry (in particular with respect to the identification of best practices in satellite testing and the development of effective data-driven reliability growth programs).