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HARDWARE DEGRADATION MODELS FOR DESIGN OPTIMIZATION OF REUSABLE SPACE SYSTEMS

Abstract

Reusable space systems have the potential to revolutionize humanities' presence in space by reducing the cost of performing a variety of missions. With such potential, several organizations are currently developing reusable space systems, such as Blue Origin with their New Glenn launch vehicle and SpaceX with their Starship lunar lander. When developing a reusable space system, engineers have traditionally estimated its useful lifetime using testing and operational data to quantify the degradation experienced by the system. Although these methods provide high fidelity estimates, they are not well suited to early design optimization, where many designs must be evaluated quickly and cheaply. Thus, there is a need to develop degradation models for such activities. To address this need, this paper develops computational models of several hardware degradation processes commonly experienced by reusable space systems.

The degradation processes modeled fall into three categories: space environment effects (i.e., vacuum, thermal cycling, and plasma effects), material effects (i.e., stress and strain, embrittlement, corrosion), and operational effects (contamination, living organisms). To model each degradation process investigated, one of three methods is used. First, if available, existing high-level equations from the literature are used. However, such equations are not available for most of the processes modeled. The next method used is to estimate degradation using observed data from in-space exposure testing missions (NASA LDEF, ISS MISSE). When neither of the previous methods are viable, a finite-element model of the underlying physical phenomenon is used to estimate the degradation experienced. As inputs, the degradation models use material properties, interaction effects between materials, and environmental parameters.

To show the utility of the developed models, they are applied to a launch vehicle turbopump blade and a spacecraft reaction wheel. These models are envisioned to assist designers of reusable space systems by enabling them to evaluate the lifetimes of many designs efficiently and gain a deeper understanding of a system's degradation behavior over time to identify possible mitigation measures.