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Failure mechanisms of $Ni\text{-}H_2$ and Li-Ion batteries under hypervelocity impacts

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Abstract

Lithium-Ion (Li-Ion) batteries have yielded significant performance advantages for many industries, including the aerospace industry, and have been selected to replace nickel hydrogen ($Ni\text{-}H_2$) batteries for the International Space Station (ISS) to meet the energy storage demands. As the ISS uses its vast solar arrays to generate its power, the solar arrays meet their sunlit power demands and supply excess power to battery packs for power delivery on the sun obscured phase of the approximate 90 minute low Earth orbit. These large battery packs are located on the exterior of the ISS, and as such, the battery packs are exposed to external environment threats like naturally occurring micrometeoroids and artificial orbital debris (MMOD). While the risks from these solid particle environments has been known and addressed to an acceptable risk of failure through shield design, it is not possible to completely eliminate the risk of loss of these assets on orbit due to MMOD motivating a study into the failure consequences to the ISS. This paper documents the different failure modes for these two types of batteries under hypervelocity impact and the implications for spacecraft survivability when shielding is breached.

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Keywords: Lithium-Ion; Nickel hydrogen; Survivability; Hypervelocity

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1. Introduction

Thermal runaway events have been experienced in terrestrial applications of the Li-Ion battery, and have been known to cause a fire that has the potential to spread to neighboring cells [1-3]. However, many aspects of the impact threat at ISS differ significantly from terrestrial failure scenarios requiring additional studies relevant to the ISS environment. Among the major differences is the configuration that is required for operation in space, the absence of an atmosphere and the impact speeds are far higher at the ISS. Owing to these differences, Li-Ion battery cells, that are representative of those selected for operation on the ISS, have been studied under conditions approximating orbital impacts.

As a basis of comparison of risk and as a result of the continued deployment, the predecessor nickel-hydrogen (Ni-H_2) cells have also been considered under similar conditions. For both types of cells, the representative shielding surrounding the battery pack is overwhelmed under the experimental impact conditions. This study has been directed by the NASA Johnson Space Center's Hypervelocity Impact Technology (HVIT) group for the International Space Station program office and the Boeing Company and performed at the 12.7 mm and 25.4 mm, two-stage, light-gas guns at the Remote Hypervelocity Test Laboratory in NASA Johnson Space Center's White Sands Test Facility, Las Cruces, NM.

2. Ni-H_2 Impact Experiments

An 81 A-hr, Ni-H_2 impact study has been performed on a legacy configuration of the ISS orbital replacement unit (ORU) battery assembly as shown in Fig. 1a. The experimental configuration of the ORU battery assembly in the test chamber is shown in Fig. 1b. This configuration is typical of the deployed ISS configuration and consists of thirty-eight cylindrical battery cells contained in a protective enclosure. The Ni-H_2 battery cells are constructed from Inconel 718 with minimum thicknesses in the cylinder of 0.8 mm and the dome of 0.65 mm. These Ni-H_2 batteries will continue to be deployed on the outside of the ISS even after they have been functionally replaced by the Li-Ion batteries; therefore, they represent a continued safety consideration for the ISS.

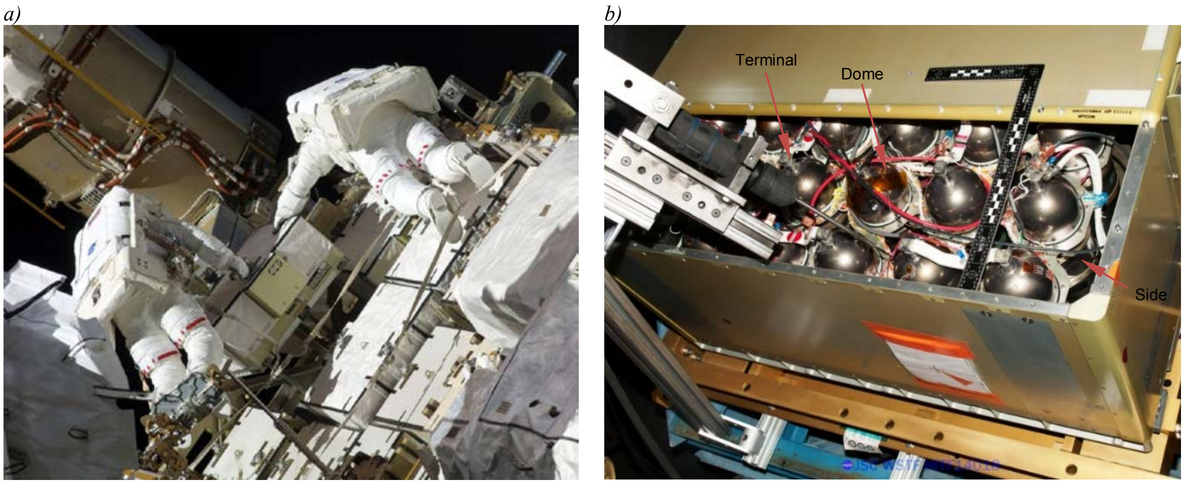

Fig. 1. (a) ISS Ni-H_2 battery ORU and (b) ORU subassembly with enclosure open.