Revisions to the Crewed Space Vehicle Battery Safety Requirements JSC 20793

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ABSTRACT

The JSC 20793, "Crewed Space Vehicle Battery Safety Requirements" was updated recently based on lessons learned in the past decade. Lessons learned were from field experiences and tests carried out by the various NASA Centers, other government agencies, as well as the aerospace industry. This paper will describe the changes made to the battery safety requirements document.

Key Words: Battery safety requirements, safety standard, space vehicle batteries, space battery safety

INTRODUCTION

The JSC 20793 was first published as a "Manned Battery Safety Handbook" in 1985. The document underwent its first major update in 2005 when it was converted into a requirements document for human-rated battery applications and then underwent a minor update in 2006. However, in the past decade, the use of lithium-ion batteries has significantly increased in the commercial and government sectors including those used in space environments. With the increasing usage of the lithium-ion battery chemistry and the fact that this battery chemistry is associated with energetic catastrophic events, extensive studies have been carried out in the battery world to understand the nature and cause of the catastrophic events. Investigations of the incidents point to negligence in choice of cell design, lack of comprehensive battery safety controls, lack of stringent testing and screening of cells and batteries. In addition to this, new cell chemistries like the Lithium-sulfur, the increased use of thermal batteries and the introduction of asymmetric capacitors has prompted the revision.

DISCUSSION OF CHANGES

The first major change is in the format. The document now carries a requirement-based format with italicized text that includes explanatory, best practice and rationale information. Each requirement has a single "shall" that can be verified clearly. The italicized text below each requirement provides the rationale and explanation for the need to have the requirement and details of best practices from past experience or literature data. This makes the document less prescriptive and more objective oriented. All the requirements with "shall" statements are localized in Sections 4 and 5 of the document. Section 4 includes all the general battery requirements such as fault tolerance, design for minimum risk and test protocols. Section 5 focuses on the catastrophic hazards and the controls for each, thus aligning it with a typical hazard report format.
Several appendices were added that included glossary, definitions of terms, details on qualification testing, details on the approval process, cell manufacturing facility audit processes, a summary table of the requirements, etc.

A. Revision C Chapters 1 to 3:

Chapter 1 remains the same except for the addition of a section on battery design evaluation and approval. Chapter 2 remains the same and includes the Applicable/Reference Documents. In the new revision, documents referring to the Shuttle/Orbiter have been deleted and new references applicable to the ISS and future exploration systems have been included. Chapter 3 is new with the introduction of a section on Acronyms and Definitions.

B. Revision C Chapter 4:

Chapter 4 in Rev C includes the general battery safety requirements. This section includes the following subsections:
Section 4.1 deals with the methodologies used in ensuring safe outcomes and provides details on the fault tolerance and design for minimum risk approaches. Section 4.2 deals with the key aspects of engineering evaluation, qualification and flight acceptance testing. Section 4.3 includes manufacturing quality with special focus on configuration control and lot testing. Section 4.4 discusses general design requirements such as electrical interconnects, wiring, lithium-ion cell and battery monitoring, cell matching, the use of dissimilar controls, etc. This section has a distribution of requirements that were formulated after some of the catastrophic events in the commercial aerospace industry. Section 4.5 and 4.6 which address mission usage and post-flight cell and pack evaluation respectively are unchanged from Revision B. Section 4.7 was added on to address ground processing requirements and Section 4.8 was added to address shelf and service life related requirements.

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C. Revision C Chapter 5:
Chapter 5 of Revision C contains all the information that had previously been located in Chapter 4 of Revision B. However, the format for the requirements underwent a major change. The hazards are now categorized as Fire/Explosion, Chemical Exposure, Electrical and Extreme Temperature. Under each of these, the hazard causes are addressed and the recommended controls and lessons learned have been included.

D. Revision C Chapter 6:
Chapter 6 of Revision C has all the contents of Chapter 5 of Revision B. The major change to this section was the conversion of all the "shall" statements to "should" or "must". Very minor corrections were made to the content for the battery chemistries from Revision B, but a few more new chemistries were added to Chapter 6 of Revision C. The new chemistry sections added were Lithium-Sulfur, thermal batteries and capacitors/ supercapacitors. A noteworthy change that was made is for the li-ion polymer chemistry section where the environment for the leak test was changed from 0.1 psi to 8 - 10 psi environments. The change was prompted by test programs carried out internally that showed changes in pouch cell performance after exposure to vacuum or deep vacuum conditions.

E. Revision C Chapters 7 and 8:
Chapter 7 included all the literature references. Chapter 8 had several appendices that was provided to help the hardware owner design the batteries safely and also provides guidance on several topics. Appendix A included the qualification and flight acceptance vibration test background and spectra for batteries, Appendix B included recommended practices for custom cell manufacturing facility audits, Appendix C included background and recommendations for shelf and service life information for commonly used battery chemistries, Appendix D included a copy of the battery design evaluation form and Appendix E has a summary matrix of all the requirements in Revision C.

F. Example of Format Change:
The format change was performed to closely follow the NASA standards format. The new format includes a short section on the background for the requirement, the actual requirement itself and then an italicized section that provides the rationale and recommendations on how to meet the requirement based on past history and experience. The following section is a given here as an example for the format change.

Section 4.3.2 Subsequent Flight Lot Testing
Some applications could require additional lots of flight batteries/cells beyond the original lot that was acceptance tested, qualified, and approved for flight. Key safety features must be retested to be sure that the new cell lots are performing like the previous qualified lot.
a. Any new battery lot and/or cell date code shall be assumed to be a new design and require a repeat of all battery and/or cell lot qualification testing and mitigation measures specified in Section 4.2.2.
An exception can be made for COTS cell batches delivered with two date codes that represent consecutive days if it can be verified they are part of a single production run.

G. Significant Additions:
A few additions were of significant importance. For instance, one of the new requirements under the internal short hazard cause section indicates that measures shall be taken to reduce the likelihood and/or severity of an internal short circuit event to a level acceptable to the program/project. And the rationale provides very detailed information on using design mitigation measures, manufacturing mitigation measures, test mitigation measures and operation of the hardware within the manufacturer's recommended limits.
A second significant addition is the inclusion of a requirement to prevent cell-to-cell thermal runaway propagation. This is a requirement that is being levied on battery designs that have greater than 80 Wh of energy and has catastrophic failure modes associated with it. In this case, the requirement is to evaluate the design to ascertain the severity of a worst-case single-cell thermal runaway event and the propensity of the design to demonstrate cell-to-cell propagation in the intended application and environment. A second requirement under this section also requires that the evaluation shall include all the necessary analysis and test to quantify the severity (consequence) to the event in the intended application and environment as well as to identify design modifications to the battery or the system that could appreciably reduce that severity.

CONCLUSIONS
The updated JSC 20793 Revision C has been accepted by the ISS and Commercial Crew and Cargo Programs. The document has all the requirements up front. The total number of requirements changed from 400 to 100 although all the information was retained. The large change was due to a repetition of the requirements in various sections of the document in the previous version. The document not only provides the requirements

clearly but also has a significant set of recommendations on how to design safely and meet the safety requirements. The new appendices are extremely informative. In conclusion, the new revision provides the hardware owner flexibility in designing their controls to meet the fault-tolerance or top level safety requirements.

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