AEROSPACE REPORT NO.
TR-RS-2020-00030

# Lithium-Ion Battery Tailoring for AIAA S-122-2007, Electrical Power Systems for Unmanned Spacecraft

July 31, 2020

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Prepared for:
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Contract No. FA8802-19-C-0001

Authorized by: Space Systems Group



This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. FA8802-19-C-0001 with the Space and Missile Systems Center, 483 N. Aviation Blvd., El Segundo, CA 90245. It was reviewed and approved for The Aerospace Corporation by Anthony T. Salvaggio, Jr., Principal Director. Franco R. Macchia was the project officer for the SMC Atlas Corps Directorate of Engineering.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas until adopted or otherwise implemented by the government.

Approved Electronically by
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13 Oct 2020

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# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE (*DD-MM-YYYY*) | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| 31-07-2020 | | |

**4. TITLE AND SUBTITLE**

Lithium-Ion Battery Tailoring for AIAA S-122-2007, Electrical Power Systems for Unmanned Spacecraft

**5a. CONTRACT NUMBER**
FA8802-19-C-0001

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**

James M. Walker

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

The Aerospace Corporation
2310 E. El Segundo Blvd.
El Segundo, CA 90245-4691

**8. PERFORMING ORGANIZATION REPORT NUMBER**

TR-RS-2020-00030

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

Space and Missile Systems Center
United States Space Force
483 N. Aviation Blvd.
El Segundo, CA 90245

**10. SPONSOR/MONITOR'S ACRONYM(S)**
SMC

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

This document is to be used for tailoring AIAA S-122-2007, *Electrical Power Systems for Unmanned Spacecraft*, to provide an effective baseline for space vehicle (SV) electrical power system designs that employ lithium-ion batteries. The focus is on battery solutions with large-format cells that need monitoring, telemetering, and balancing to operate safely. For battery solutions that have small-format cells with internal safety features, in a battery topology that provides safe self-balancing of the cells, then cell-level monitoring, telemetering, and balancing are not required if appropriate test and/or analysis are available to support this premise. This document is intended for use by SV contractors and sub-contractors for spacecraft with architectures/designs including power management and distribution (PMAD) systems and lithium ion batteries.

**15. SUBJECT TERMS**
Electrical power system; Lithium-ion battery; Space vehicle; Standard; Tailoring

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| | | | | | James M. Walker |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER *(include area code)* |
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | | 37 | (310) 336-5253 |

**Standard Form 298 (Rev. 8-98)**
**Prescribed by ANSI Std. 239.18**

## Change History

| Rev No | Description of Change | Effective Date |
|---|---|---|
| - | Initial release<br><br>These requirements were transferred from TOR-2007(8583)-1, "Lithium-Ion Battery Standards for Spacecraft Applications" to better align with the standard to which they apply.<br><br>Stakeholder review was documented in TOR-2019-01294-Rev A, "Stakeholder Review: Lithium-Ion Battery Tailoring for AIAA S-122-2007, Electrical Power Systems for Unmanned Spacecraft". | 07-31-2020 |

# Contents

# 1. Scope

## 1.1 Purpose

This document is to be used for tailoring the AIAA Standard S-122-2007, 5 January 2007, to provide an effective space vehicle (SV) program baseline for electrical power systems design employing Li-Ion batteries.

The focus is on battery solutions with large-format cells that need monitoring, telemetering, and balancing in order to operate safely. For battery solutions that have small-format cells with internal safety features, in a battery topology that provides safe self-balancing of the cells, then cell-level monitoring, telemetering, and balancing are not required if appropriate test and/or analysis are available to support this premise.

## 1.2 Application

This document is intended for use by SV contractors and sub-contractors for spacecraft with architectures/designs including power management and distribution (PMAD) systems and lithium ion batteries.

# 2. Tailoring

## 2.1 Definition

Tailoring is a process by which individual requirements from specifications, standards, or related documents are evaluated and applied to a specific program by deletion, modification, or addition of requirements. Tailoring of requirements should be undertaken with consultation and approval of the procuring authority, to align the standard with the acquisition authority's requirements and mission needs.

The tailored AIAA Standard establishes a baseline for requirements, which may be further tailored or revised with rationale upon approval by the procuring authority.

## 2.2 Changes from AIAA S-122-2007

The following is a comprehensive list of all the changes that this document imposes on AIAA S-122-2007:

| Section | Title | Change Type |
|---|---|---|
| 3. | Applicable Documents | Added Applicable Documents |
| 4.1 | Acronyms and Abbreviated Terms | Added Acronyms |
| 4.2 | Terms and Definitions | Added definition |
| 5.1.2 | Energy Storage | Removed reference to reconditioning<br>Clarification language added |
| 5.1.3 | Power Management and Distribution (PMAD) | Clarification language added |
| 5.1.4 | Flight Software | Clarification language added |
| 5.2.1.1 | Worst Eclipse | Revised Title and added requirement |
| 5.2.1.3.1 | Battery Recharge | Clarification language added |
| 5.2.1.4.1 | Thermal Cycles | Requirement added |
| 5.2.5.5 | Environments | Clarification language added |
| 5.2.6.2 | Battery Loads | Revised requirement |
| 5.2.6.5 | Energy Reserve | Requirement added |
| 5.2.6.6 | Thermal Control | Revised requirement |
| 5.2.6.7 | Battery Reconditioning | Requirement deleted |
| 5.2.6.7.1 | Single-Battery Systems | Requirement deleted |
| 5.2.6.7.2 | Recharge of partial batteries | Requirement deleted |
| 5.2.6.7.3 | Multi-Battery Systems | Requirement deleted |
| 5.2.6.7.4 | Reconditioning Plan | Requirement deleted |
| 5.2.6.8 | Battery Cell Fault Management | Revised requirement |
| 5.2.6.8.1 | Autonomy of Bypass Devices | Revised requirement |
| 5.2.6.9.2.1 | Battery Charging | Requirement added |
| 5.2.7.1.2.2 | Load Interface Stability | Requirement added |
| 5.2.7.2 | Battery Management | Requirement added |
| 5.2.7.2.1 | Battery Charge Management Autonomy | Requirement added |
| 5.2.7.2.2 | Ampere Hour Integration | Requirement revised |
| 5.2.8.5.1 | Fuses | Revised Requirement |
| 5.2.11.1 | Telemetry | Requirement revised |
| 5.2.11.4 | Battery Trend Data | Clarification language added |
| 5.2.11.5 | Telemetry During Ground and Launch Support | Requirement added |
| 5.2.14.2 | Fault Autonomy | Requirement added |

| Section | Title | Change Type |
|---|---|---|
| 5.2.14.3 | Fault Tolerance | Requirement added |
| 5.2.14.4 | Spacecraft Autonomy | Requirement added |
| 5.2.14.4.1 | Dead Bus Recovery | Requirement revised |
| 5.4.2 h) | Launch Complex | Revised Requirement |
| 5.4.3.1 | Ground Support Equipment (GSE) | Requirement added |
| 5.5.4.1 | Battery Storage and Handling | Requirement added |
| 5.5.4.1.1 | Storage | Requirement revised |
| 5.5.4.1.2 | Discharge with a Battery Conditioning Module (BCM) | Requirement revised |
| 5.5.4.1.3 | Shorting Plugs | Requirement deleted<br>Note added |
| 5.5.4.1.6 | Conditioning Prior to Installation on the Vehicle | Requirement added |
| 5.5.4.1.8 | Transportation to Launch Site | Requirement added |
| 5.5.4.1.9 | Records | Requirement added |
| 5.5.4.1.11 | Battery Handling Plan | Requirement revised |
| 5.5.6.1 | Packaging | Requirement added |
| 6. | Verification | Typo corrected |
| 6.3.1.4 | Stability Testing | Requirement added |
| 6.3.1.10 | Flight Battery Verification Tests | Requirement added |
| 6.4.10 | Battery Leakage Current Analysis | Requirement added |
| 7.2.3 | Interface Stability | Corrected equation |
| 7.6 | EPS Worst-Case Analysis | Added item for battery analysis |

## 3. Applicable Documents

Add the following to AIAA S-122-2007:

[1] TOR-2018-00316 Dead Bus Recovery Requirements for Earth Orbiting Spacecraft

## 4. Vocabulary

### 4.1 Acronyms and Abbreviated Terms

Add the following to AIAA S-122-2007 section 4.1:

| | |
|---|---|
| DBP | Depleted Battery Prevention |
| DBR | Dead Bus Recovery |
| DITL | Day in the Life |

### 4.2 Terms and Definitions

Add the following to AIAA S-122-2007 section 4.2:

**Cell Bank** Two or more cells electrically connected into a single-parallel string (see virtual cell).

## 5. Purpose of EPS

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.1 Functional Description

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.1.1 Power Generation/Energy Conversion

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.1.2 Energy Storage

Replace the first paragraph of AIAA S-122-2007 section 5.1.2 with the following:

Energy storage devices store some of the energy generated by the power generation element for use in powering the loads during eclipse periods and during sunlight operation when the output of the power generation element is insufficient to meet the overall load demand.

Replace the last paragraph of AIAA S-122-2007 section 5.1.2 with the following:

Batteries should be sized based on predicted worst-case mission requirements and expected capacity degradation over mission life. Batteries are designed to support the spacecraft through the launch sequence, including all anticipated contingencies and through all foreseen losses of solar energy during the mission,

including those resulting from failures. Where system requirements dictate a battery tolerate a single fault, the battery is designed to operate with one cell either failed shorted or open. Provisions for monitoring the critical battery performance parameters are also included in the design. Battery thermal design should take into account maximum and minimum temperature of operation under all intended operating conditions and maximum allowed temperature gradients between different parts of the same cell, between cells or groups of cells within a battery, between batteries, and as a result of any failure modes. The charging technique is designed to ensure that the depth of discharge and the recharge ratio applied are appropriate for the particular cell technology, temperature of operation, and mission life requirements. For Lithium-Ion batteries, the charging technique is also designed to ensure max and min cell voltages stay within values that support mission life of the battery cells during normal operations.

### 5.1.3 Power Management and Distribution (PMAD)

Replace AIAA S-122-2007 fifth sentence of section 5.1.3, "Telemetry generally includes…", with the following:

Telemetry generally includes bus and battery voltage, power source and load currents, battery charge and discharge currents and cell voltages, power electronics operating temperatures, and status of fault detection and protection electronics.

### 5.1.4 Flight Software

Append the following sentences to the end of AIAA S-122-2007 section 5.1.4:

Note: For Lithium-Ion Batteries, generally a taper charge algorithm of either pseudo ideal or step reduction in applied charge current as a function of voltage (and temperature) should be incorporated. Taper charging is required to ensure maximum energy into the cells for the mission design needs. Individual over and under charge, cell voltage detection should also be incorporated into flight software to preclude over-charging or under-charging any individual cell to preclude cell damage or safety concerns.

### 5.1.5 Harness

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 5.2 Functional and Performance Requirements

### 5.2.1 Orbital Profile

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.1.1 Worst Eclipse

Append to title " and Off-Sun Pointing".

Append the following to the end of AIAA S-122-2007 section 5.2.1.1:

In addition, the worst-case off-sun pointing shall be considered in the analysis coupled with the worst-case eclipse period for a normal Day in the Life (DITL) or required series of DITL operations or orbits.

#### 5.2.1.2 Maximum Sun-outage Time

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.1.3 GEO-Specific Requirements

##### 5.2.1.3.1 Battery Recharge

Append the following to the end of AIAA S-122-2007 section 5.2.1.3.1:

NOTE: The worst case off pointing from the sun should be considered by analysis coupled with the worst case eclipse period with reduced operations below normal operations allowed.

##### 5.2.1.3.2 Relocation (with electric propulsion)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.1.4 LEO-Specific Requirements

##### 5.2.1.4.1 Thermal Cycles

Append the following to the end of AIAA S-122-2007 section 5.2.1.4.1:

c) For power electronics, the Combined Damage Index (CDI) life expectancy analysis shall include impacts of electrical current flowing through the unit or system to ensure that the thermal analysis is bounded and accounts for stress.

##### 5.2.1.4.2 Energy Balance

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.1.5 Lunar Eclipses

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.1.6 Re-entry disposal

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.1.7 Environments

##### 5.2.1.7.1 Radiation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.1.7.2 Total Dose

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.1.7.3 Single Event Effects (SEE)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.2 Mission Life

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.3 Mission Phases

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.4 EPS Architecture

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.4.1 Voltage Choice

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.5 Power Generation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.5.1 Array Configuration

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.5.2 Array Sizing

##### 5.2.5.2.1 Sizing for Load Margin

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.5.2.2 Contingent Source Power

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.5.2.3 Failed Cells and Strings

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.5.3 Array Max Power and Voltage

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.5.4 Electrostatic Discharge (ESD) Control

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.5.5 Environments

Append the following to the end of AIAA S-122-2007 section 5.2.5.5:

NOTE: Load demand may exceed the array power during operations if it is shown that overall EPS power balance with margin is maintained.

### 5.2.6 Energy Storage

#### 5.2.6.1 Battery Cell Technology

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.2 Battery Loads

Replace AIAA S-122-2007 section 5.2.6.2 c) with the following:

c) failed cell(s) per battery or failed battery per 5.2.6.2.2 or 5.2.6.8 b).

#### 5.2.6.2.1 Battery Redundancy

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.2.2 Failed Batteries

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.6.3 Depth of Discharge Calculation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.6.4 Maximum DOD

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.6.5 Energy Reserve

Replace AIAA S-122-2007 section 5.2.6.5 b) with the following:

b) The calculation of energy reserve shall be based on the discharge voltage curve of the selected cell technology including applicable mission degradation estimates at the expected operating conditions.

Append the following to the end of AIAA S-122-2007 section 5.2.6.5:

c) a) and b) above shall be met starting at the lowest expected state of charge (e.g., voltage for lithium-ion) just prior to the worst-case off-nominal event requiring energy reserve (e.g., safe hold event or other).

### 5.2.6.6 Thermal Control

Replace AIAA S-122-2007 section 5.2.6.6 with the following:

Battery temperatures throughout the orbital lifetime shall be maintained within a temperature range previously established from vehicle, battery, cell bank (virtual cell), cell development, and life testing. Control and contingency procedures to maintain battery temperature within the required range shall be the basis for battery operations and control, while at the launch site and on orbit.

The battery shall be designed with redundant heater circuits to prevent under temperature of the battery or a battery cell during operation.

### 5.2.6.7 Battery Reconditioning

Delete AIAA S-122-2007 section 5.2.6.7.

#### 5.2.6.7.1 Single-Battery Systems

Delete AIAA S-122-2007 section 5.2.6.7.1.

#### 5.2.6.7.2 Recharge of partial batteries

Delete AIAA S-122-2007 section 5.2.6.7.2.

#### 5.2.6.7.3 Multiple-Battery Systems

Delete AIAA S-122-2007 section 5.2.6.7.3.

#### 5.2.6.7.4 Reconditioning Plan

Delete AIAA S-122-2007 section 5.2.6.7.4.

### 5.2.6.8 Battery Cell Fault Management

Replace AIAA S-122-2007 section 5.2.6.8 with the following:

a) Battery cell bypass shall be provided on each cell or parallel group of cells in the battery or batteries unless it can be shown that the mission reliability requirement can be met without cell bypass devices

b) In all cases the power budget and energy balance analysis shall account for the maximum number of failed cells or batteries and shall include the dissipation of the bypass devices or failed cells (i.e. high resistive shorts for non-bypassed cells).

#### 5.2.6.8.1 Autonomy of Bypass Devices

Replace AIAA S-122-2007 section 5.2.6.8.1 with the following:

Manual (i.e. commandable) as well as autonomous bypass techniques (e.g., diode and/or heat activated devices) are acceptable; however, where manual techniques are employed, sufficient cell telemetry shall be provided to ground personnel to allow proper system diagnosis and commanding of bypass devices. For single battery systems or where the analysis indicates manual activation of a cell bypass device cannot be timely, autonomous bypass shall be incorporated.

#### 5.2.6.8.2 Short Circuit of Energized Cells

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.6.9 Battery Operational Modes

#### 5.2.6.9.1 Ground Storage

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.9.2 Ground Test and Prelaunch

#### 5.2.6.9.2.1 Battery Charging

Append the following to the end of AIAA S-122-2007 section 5.2.6.9.2.1:

Battery contingency plans shall be written for pre-launch activities in the event of a launch scrub or abort, pre or post transfer to internal power or demating and extended storage at the launch site.

Prior to launch, voltage variations between all cells or cell banks (virtual cells) shall be within the appropriate technology and mission required limits.

Note: It is recommended that the voltage variations between all cells or cell banks (virtual cells) be within 0.030 V.

#### 5.2.6.9.2.2 Battery Safing

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.9.3 Launch, Ascent, Transfer Orbit

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.9.3.1 Maximum DOD

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.9.4 On-Station and Safe-Hold Modes

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.9.5 On-Orbit Storage

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.9.6 On-Orbit Disposal

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.6.10 Battery Life

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.7 Power Management

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.7.1 Power Control

#### 5.2.7.1.1 Bus Regulation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.7.1.2 Bus Stability

#### 5.2.7.1.2.1 Feedback Stability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.7.1.2.2 Load Interface Stability

Append the following to the end of AIAA S-122-2007 section 5.2.7.1.2.2:

The power interface loop gain at the main bus, and at other distribution points between the EPS and the loads shall be stable over the full range of operating conditions with the following EOL stability margins (refer to section 7.2.3):

Case 1: source load impedance non-interacting case

The interface loop gain margin (Tm=Zs/ZL, refer to section 7.2.3) shall be greater than 6 dB at the frequency of phase crossing of minus 180 degrees.

Case 2: source load impedance interacting case

The minimum phase margin shall be greater than 45 degrees at the frequencies of two zero dB crossings

#### 5.2.7.2 Battery Management

Append the following to the end of AIAA S-122-2007 section 5.2.7.2.

Battery charging control and contingency procedures shall be developed based upon battery test data. Battery or individual cell voltages and charge currents shall not exceed manufacturer's recommended limits unless validated by test and impact to mission life.

##### 5.2.7.2.1 Battery Charge Management Autonomy

Append the following to the end of AIAA S-122-2007 section 5.2.7.2.1 c):

Space vehicle battery voltage, cell or cell bank (virtual cell) voltages, current, and cell temperatures shall be monitored by spacecraft processor at least every 15 seconds during launch and during all sun and eclipse operations unless longer periods for battery management, safety and health can be technically justified.

In the event of an under-temperature condition, charge current shall be limited to mitigate lithium plating of electrode surfaces.

##### 5.2.7.2.2 Ampere Hour Integration

Append the following to the end of AIAA S-122-2007 the end of section 5.2.7.2.2:

Further, for lithium-ion (or technologies where voltage is a function of percent state of charge) systems incorporating Ampere Hour Integration, the charge system shall be reset periodically to a known state of charge to remove propagation error from the integrator to preclude inadvertent under or overcharge.

NOTE: Propagation reset is generally most accurate when the battery is neither charging nor discharging (i.e. open circuit).

#### 5.2.7.3 Under-Voltage Management

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.8 Power Distribution

#### 5.2.8.1 Load Groups

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.8.2 Essential Loads

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.8.2.1 Essential Load Operate Through

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.8.3 Wire Harnesses and Connectors

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.8.4 Wire Temperatures

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.8.5 Overcurrent Protection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.8.5.1 Fuses

Replace AIAA S-122-2007 section 5.2.8.5.1 c) with the following:

c) to disconnect any overloaded circuit before distribution wiring or trace reaches over-temperature.

##### 5.2.8.5.2 Circuit Breakers and Current Limiting Devices (Other Than Fuses)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.8.5.3 Electronic Switches

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.8.5.4 Fault Coordination

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.8.6 Protection Against Insulation Failure

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.8.7 Protection against plasma arcs

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.9 Grounding and Bonding

#### 5.2.9.1 Grounding

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.9.2 Bonding

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.10 Energy Management

#### 5.2.10.1 Power Margin

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.10.2 Power Budget

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.10.3 Adjusted Load Estimate

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.10.3.1 Heater Loads

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.10.4 Contingent Load Power

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.10.5 Load Margin

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.10.6 Parasitic Power Loss

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.11 Telemetry and Command

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.11.1 Telemetry

Replace AIAA S-122-2007 EPS Status/Performance subitem b) with the following:

b) Data to infer the State-of-Charge of the energy storage element:

- battery energy storage: the individual battery virtual cell voltages
- flywheel energy storage: the flywheel angular velocities
- fuel cell energy storage: reactant levels

Replace AIAA S-122-2007 EPS Health Monitoring subitems a) and b) with the following:

a) Every battery cell (or cell bank – virtual cell) shall have cell or bank voltage and temperature telemetry that is monitored and available via ground telemetry.

   A reduction in temperature telemetry can be considered based on battery configuration where at a minimum a primary and redundant temperature sensor is available for each of the following functions: heater zone control, charge control and dead bus recovery, as long as the response time to any cell overtemperature is at an acceptable risk level for the program.

b) Battery Cell-voltage accuracy at the on-board computer and for ground telemetry shall be within ±0.010 V.

c) Battery Cell temperature accuracy at the on-board computer and for ground telemetry shall be within ±3°C.

d) Spacecraft cell-level balancing and cell-level voltage circuitry shall be redundant.

#### 5.2.11.2 Command

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.11.3 Solar Array I/V Curve Measurement

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.11.4 Battery Trend Data

Replace AIAA S-122-2007 section 5.2.11.4 a) with the following:

a) Space vehicle battery voltage, cell or cell bank (virtual cell) voltages, current, cell temperatures, together with depth-of-discharge performance, shall be summarized, trended, and evaluated to provide performance trends and a basis for on-orbit operations. The update rate for this data shall be not less than once every minute for voltage, current, and temperature.

#### 5.2.11.5 Telemetry During Ground- and Launch-Support

Append the following sentences to the end of AIAA S-122-2007 section 5.2.11.5:

Battery voltage, cell or cell bank (virtual cell) voltage, current, and cell temperatures shall be measured periodically after battery installation on the vehicle, up to the final terminal countdown, to verify state-of-health of the electrical systems prior to launch. The data shall be evaluated to provide state-of-health verification of the electrical systems prior to launch.

### 5.2.12 Power Quality

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.1 Under-Voltage

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.2 Over-Voltage

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.3 Ripple

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.4 Transient Requirements

##### 5.2.12.4.1 Step Load Transients

There are no changes to this section – Use AIAA S-122-2007 verbatim.

###### 5.2.12.4.1.1 Overshoot Surges

There are no changes to this section – Use AIAA S-122-2007 verbatim.

###### 5.2.12.4.1.2 Undershoot Surges

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.2.12.4.2 Fault-Clearing Transients

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.4.2.1 Over-Voltage Surges

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.4.2.2 Under-Voltage Surges

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.4.3 Short-Duration Aperiodic Spikes

#### 5.2.12.4.3.1 Positive-Going Spikes

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.12.4.3.2 Negative-Going Spikes

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.12.5 Structure Spikes

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 5.2.13 EMI/EMC

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.13.1 Lightning Protection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 5.2.14 Fault Detection, Isolation, and Recovery

### 5.2.14.1 Fault Protection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.2.14.2 Fault Autonomy

Append the following sentences to the end of AIAA S-122-2007 section 5.2.14.2:

Battery, cell bank (virtual cell) and cell voltages, charge and discharge currents, and temperatures that violate the established yellow and red limits shall result in an alert to the spacecraft operators. All battery, cell bank (virtual cell) and cell voltages, current and temperature telemetry shall be individually assessed by flight software and autonomous action taken when yellow and/or red limits are exceeded.

Individual telemetry points shall not be eliminated and/or filtered by fault detection software unless it is determined to be an incorrect reading based on engineering logic agreed upon ahead of time, or upon review.

### 5.2.14.3 Fault Tolerance

Append the following sentences to the end of AIAA S-122-2007 section 5.2.14.3:

c. The spacecraft shall autonomously reduce charge current or disable charging in the event of an overvoltage detected at the cell as well as independently at the battery level.

d. The spacecraft shall autonomously respond to a high-charge current by switching to a redundant-charge circuit or disabling charge within two minutes of violation.

### 5.2.14.4 Spacecraft Autonomy

Append the following sentences to the end of AIAA S-122-2007 section 5.2.14.4:

The spacecraft shall be capable of autonomously responding to a battery-cell short (i.e., cell voltage deviates from average cell voltage by 20 percent state-of-charge) or other high-temperature scenario (i.e., exceeds acceptance temperature by 10°C and no greater than 45°C) with a response criteria as follows:

1. The on-board computer shall initiate a response within two minutes of a voltage, temperature or current violation to limit battery state-of-charge to a level that mitigates potential for cell venting and propagation.

2. The on-board computer shall maintain the battery at a state-of-charge that precludes thermal runway until the cell or battery has been deemed safe.

3. For a battery-redundant design, the battery shall be capable of being removed from the charge discharge path via a relay or switch.

4. For a cell or cell bank (virtual cell)-redundant battery design, the battery shall be capable of removing a cell from the electrical circuit such as by an autonomous or commanded-cell bypass or isolation switch.

Alternative designs can be considered if battery management, safety, and health can be validated.

#### 5.2.14.4.1 Dead Bus Recovery (DBR)

Replace AIAA S-122-2007 section 5.2.14.4.1 with the following:

In the event of depleted batteries, potentially from loss of sun on the solar arrays, provision shall be made for recovery of EPS functionality if sun is restored. The Aerospace Corporation report *Dead Bus Recovery Requirements for Earth Orbiting Spacecraft*, [Reference 1][1] defines power subsystem requirements to allow for recovery from a dead bus. The following requirements protect battery cells that are susceptible to permanent degradation or damage due to overdischarge (e.g., Li-Ion battery cells):

1. If the satellite experiences an abnormally low battery SOC that drops below a predetermined minimum threshold, the satellite shall be capable of autonomously enabling Depleted Battery Prevention (DBP). DBP is a means whereby the satellite can protect a battery from overdischarge by completely blocking its discharge path.

   Note: The minimum SOC threshold will be determined based upon the specific battery cell technology, power system architecture, and fault management approach. Once determined, the specific minimum SOC threshold will be documented in the applicable system and unit specifications.

2. The state of health of the battery shall be considered when recharging the battery during dead bus recovery including the following:
   a. Battery cell temperature is within applicable limits to safely charge the battery
   b. Maximum charge rate is not exceeded

[1] See section 3 of this document.

c. Battery charge is terminated if overcharge limit is reached

3. The satellite shall be capable of autonomously re-enabling battery discharge when sufficient charge has been returned to the battery to initiate recovery operations.

Note: The system would have already reached thresholds resulting in shedding non-critical unit and heater loads prior to reaching the DBP threshold.

#### 5.2.14.4.2 Failure Propagation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.2.14.4.3 Power Output Following a Failure

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.3 Design and Construction Requirements

#### 5.3.1 Parts, Materials and Processes (PMP)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.1.1 Materials and Parts Selection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.1.1.1 Dissimilar Metals

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.1.1.2 Magnetic Materials

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.1.2 Limited Life Items

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.1.3 Forbidden Materials

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.2 Product Markings

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.3 Manufacturing Management

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.4 Interchangeability & Replaceability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.3.5 Testability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.3.6 Maintainability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.6.1 Accessibility

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.3.7 Safety

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.7.1 Range Safety

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.3.8 Human Performance/Human Engineering

#### 5.3.8.1 Connector Mis-Mating

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.8.2 Connector Protection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.8.3 Non-flight Test Connectors

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.8.4 Test Access

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.3.8.5 Contamination Control

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 5.4 Interface Requirements

### 5.4.1 Launch Vehicle

#### 5.4.1.1 Protection Devices

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.1.2 Telemetry Lines

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.1.3 Testing of Redundant Paths

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.1.4 Loss of Launch Vehicle Power During Ascent

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.1.5 Space Vehicle Battery Protection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.4.2 Launch Complex

Replace AIAA S-122-2007 section 5.4.2 h) with the following

h. The cell temperatures and voltages for a lithium-ion battery shall be monitored as an additional safety check.

#### 5.4.2.1 Thermal Interface

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.4.3 Ground Support Equipment (GSE)

#### 5.4.3.1 Protection Devices

Append the following sentences to the end of AIAA S-122-2007 section 5.4.3.1:

Check-out of all maintenance equipment, software, and safety inhibits, shall be performed before connecting flight hardware.

##### 5.4.3.1.1 Voltage Protection to Spacecraft

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.4.3.1.2 Current Protection to Spacecraft

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.4.3.1.3 AC Voltage Transient Surge Suppression

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.4.3.1.4 Reverse Polarity Protection Diode

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.4.3.1.5 Emergency Shutdown

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.4.3.1.6 Battery Safing

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.3.2 Failure Modes and Effects Analysis

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.3.3 Stability with GSE

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.4.4 Inter-subsystem Interface Requirements

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.4.1 Load Interface Requirements

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.4.4.1.1 Conducted Susceptibility Requirements

There are no changes to this section – Use AIAA S-122-2007 verbatim.

###### 5.4.4.1.1.1 Tailoring of CS Limits

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.4.4.1.2 Load Input Filter Damping

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 5.5 Physical Requirements

### 5.5.1 Power Consumption

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.1.1 Power Distribution Losses

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.1.2 Efficiency

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.5.2 Mass

#### 5.5.2.1 EPS Mass Contributors

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.2.2 EPS Mass Values

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.5.3 Volume

#### 5.5.3.1 Power Generation Source Volume

##### 5.5.3.1.1 Power Generation Source Volume – Stowed

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 5.5.3.1.2 Power Generation Source Volume – Deployed

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.3.2 Energy Storage System Volume

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.3.3 Power Management and Distribution (PMAD)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.5.4 Handling

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.4.1 Battery Storage and Handling

Append the following sentence to the end of AIAA S-122-2007 section 5.5.4.1:

Storage, handling and maintenance for the battery, battery cell bank (virtual cell), and battery cell shall conform to the handling, storage, and maintenance requirements.

#### 5.5.4.1.1 Storage

Replace AIAA S-122-2007 section 5.5.4.1.1 a) with the following:

a) When not in use for greater than three months, the batteries, cell banks (virtual cells), or cells shall be placed in appropriate temperature-controlled conditions at a state-of-charge for the storage conditions and planned storage duration unless validated by qualification life-test data/analysis to show the battery meets intended service life.

Replace AIAA S-122-2007 section 5.5.4.1.1 c) with the following:

c) Batteries shall not be used for flight, if the time between battery cell formation and launch exceeds the specified shelf-life limit for the battery under the specified temperature conditions unless verified by the qualification life-test data/analysis, recent battery performance data and approved by a waiver/deviation.

Append the following to the end of AIAA S-122-2007 section 5.5.4.1.1.

d) During storage and handling, voltage monitoring and periodic recharge, or cell rebalancing, shall be required to minimize degradation, in accordance with the battery handling and storage procedure.

e) The voltage decay rate for cells, cell banks (virtual cells) and batteries shall be periodically monitored pre- and post-shipping, during storage and battery-level manufacturing, and documented to be within specification for each cell, cell bank (virtual cell) and battery following completion of cell acceptance through launch.

#### 5.5.4.1.2 Discharge with a Battery Conditioning Module (BCM)

Replace AIAA S-122-2007 section 5.5.4.1.2 a) and b) with the following:

a) Any discharge of batteries (cell banks – virtual cells or cells) shall be accomplished with a battery conditioning-module that will discharge the battery or individual cells at controlled currents to a specified voltage level instead of being allowed to self-discharge.

b) As a safety feature, devices shall be incorporated in the design of battery conditioning modules to accommodate the discharge of the battery at any state-of-charge without causing any damage to the battery or vehicle, including the prevention of undervoltages. Redundant safety devices and inhibits shall be incorporated in the battery conditioning module to prevent damage to the battery or vehicle, and prevent any battery-cell voltage from exceeding upper- or lower-voltage limits for all battery states-of-charge, and prevent maximum-charge, or discharge currents and temperatures from exceeding specification limits.

#### 5.5.4.1.3 Shorting Plugs

Delete AIAA S-122-2007 section 5.5.4.1.3.

NOTE: shorting plugs are not to be used for Lithium Ion batteries.

#### 5.5.4.1.4 Handling Fixture

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.4.1.5 Terminal Cover

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.4.1.6 Conditioning Prior to Installation on the Vehicle

Append the following sentences to the end of AIAA S-122-2007 section 5.5.4.1.6:

When electrically connecting the battery to the spacecraft bus, the difference between the spacecraft bus voltage and the battery voltage shall be within specification values that are sufficiently small to limit surge currents to levels that will not result in damage to components or connector pins.

Battery voltage and cell and/or cell bank (virtual cell) voltage, current, and temperature, shall be measured after battery installation on the vehicle at a frequency and resolution to detect a cell-level anomaly, such as premature discharge.

#### 5.5.4.1.7 Minimum Use of Flight Batteries for Testing of Vehicle

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.4.1.8 Transportation to Launch Site

Append the following sentence to the end of AIAA S-122-2007 section 5.5.4.1.8:

e) When accessible, the batteries and/or cells shall be inspected following transportation to verify the inspection criteria.

#### 5.5.4.1.9 Records

Replace AIAA S-122-2007 section 5.5.4.1.9 b) with the following:

b) Time-correlated records shall be maintained throughout battery and spacecraft testing indicating battery, cell bank (virtual cell), cell charge and discharge currents, battery voltage, temperature and open circuit time to a sufficient accuracy to allow an assessment of potential degradation when discharging, recharging, cell-balancing, and electrical performance testing is completed.

Append the following to the end of AIAA S-122-2007 section 5.5.4.1.9:

c) Cell or cell bank (virtual cell) voltages shall be measured and recorded during cell, cell bank (virtual cell) and battery storage to identify low-voltage cells or cell banks (virtual cells) before they violate the minimum voltage threshold due to self-discharge.

d) Records shall be maintained and periodically verified to ensure the storage conditions.

e) For systems with no cell balancing, cell or cell bank (virtual cell) voltage divergence shall be measured and recorded and all cells maintained to a predetermined maximum cell voltage divergence prior to launch.

#### 5.5.4.1.10 Not for Flight Marking

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.4.1.11 Battery Handling Plan

Replace AIAA S-122-2007 the first paragraph of section 5.5.4.1.11 with the following:

A battery handling plan shall be developed and include the following items:

Append the following item to AIAA S-122-2007 section 5.5.4.1.11:

- Electrostatic Discharge Control (ESD)

Delete the following items and subitems from AIAA S-122-2007 section 5.5.4.1.11:

- Battery Wake-Up Cycle
  - Describe Wake-up Cycle procedure
  - Battery Parameter Monitoring
- Battery Reconditioning
  - Describe Reconditioning procedures
  - Battery Parameter Monitoring

Delete the following sub-items from “Battery Charging while mounted on the Satellite”:

- Reconditioning capability
- Frequency of reconditioning

Delete the following sub-items from “Battery Charging while mounted on the Launch Vehicle”:

- Reconditioning capability
- Frequency of reconditioning

### 5.5.5 Preservation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 5.5.6 Transportation

#### 5.5.6.1 Packaging

Append the following sentences to the end of AIAA S-122-2007 section 5.5.6.1.

Specialty containers shall be used during extended storage and transportation to provide physical protection to prevent damage during handling, transportation, and storage.

Shipping containers shall contain sensors to measure temperature, humidity, and mechanical shock during shipping of cells, cell banks (virtual cells) and batteries.

#### 5.5.6.2 Marking and Labeling

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.6.3 Shipping Control

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 5.5.6.4 Shipment

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 6. Verification

Replace the word “addresses” with the word “addressed” in the second sentence of the last paragraph of AIAA S-122-2007 section 6.

### 6.1 Verification Responsibility

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.2 Verification Method Definitions

#### 6.2.1 Test

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.2.1.1 Test As You Fly (TAYF)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.2.2 Inspection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.2.3 Demonstration

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.2.4 Analysis

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.2.5 Similarity

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 6.3 Test

### 6.3.1 EPS Test Requirements

#### 6.3.1.1 Test As You Fly

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.2 General EPS Testing

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.3 EMC/Power Quality Testing

##### 6.3.1.3.1 General EMC Requirements

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 6.3.1.3.2 Ripple Testing

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 6.3.1.3.3 Transient Testing

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.4 Stability Testing

Append the following sentence to the end of AIAA S-122-2007 section 6.3.1.4.

d) The Bode plot test of the feedback control loop shall meet the stability margin requirement of section 5.2.7.1.2.1 c).

#### 6.3.1.5 Battery Life Test

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.6 Solar Array Qualification

##### 6.3.1.6.1 Solar Cell Qualification

There are no changes to this section – Use AIAA S-122-2007 verbatim.

##### 6.3.1.6.2 Solar Panel Qualification

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.7 Engineering Model Tests

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.8 EPS Subsystem Test Bed

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.9 Thermal Balance Test (TBT)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.3.1.10 Flight Battery Verification Tests on Spacecraft

Add the following requirements:

The flight battery shall go through electrical checkout as part of electric power subsystem checkout after vehicle installation to verify operation of electrical charge and discharge path, nominal telemetry readings, heater operation, operation of cell-balance circuit and any inhibit circuits as follows:

a) All battery charge and discharge circuitry shall be verified as operational at nominal current levels.

b) All battery temperature sensors shall be verified as operational.

c) All battery heater circuits shall be verified as operational.

d) Cell-balance circuitry shall be verified as operational at spacecraft level.

e) Supporting battery circuitry used for dead-bus recovery shall be verified as operational at spacecraft level. Note: The flight battery should not be taken to critically high or low voltages during the test to avoid damage.

f) All battery safety fault management responses shall be verified.

## 6.4 Analysis

### 6.4.1 Power Margin Analysis

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.2 Voltage Drop

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.3 Parts Stress

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.4 Limited Life Items

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.5 Electrical Fault Analysis

#### 6.4.5.1 Harness Stress

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.4.5.2 Fault Protection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.6 FMECA

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.7 Worst Case Analysis (WCA) for Circuits

#### 6.4.7.1 General

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.4.7.2 Feedback Stability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.4.7.3 Interface Stability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.4.7.4 Bus Transient

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.4.7.5 Fault Protection

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 6.4.7.6 Wire Heating

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.8 Solar Array Statistical Damage Assessment

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.9 Solar Array Radiation Environment

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 6.4.10 Battery Leakage Current Analysis

Add the following requirement:

An analysis shall be performed to determine the impact of leakage current due to parasitic unit loads on battery cell voltage divergence.

## 7. Best Practices

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.1 Energy Balance Analysis

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.1.1 Design Reference Cases

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.1.2 Worst-Case Approach

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.1.3 Analysis Quantities

#### 7.1.3.1 General Quantities

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.2 Stability

### 7.2.1 Feedback Stability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.2.2 Intermode Stability

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.2.3 Interface Stability

Replace the equation "|Zs| . |ZL| >= 1" in AIAA S-122-2007 section 7.2.3 with the following:

|Zs| / |ZL| >= 1

## 7.3 Power Quality

### 7.3.1 Bus Ripple

There are no changes to this section – Use AIAA S-122-2007 verbatim.

#### 7.3.1.1 Conducted Susceptibility Requirements for Loads

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.3.2 Transients

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 7.4 Grounding, Bonding, and Isolation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.4.1 VRS Architectures

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.4.2 Isolation

There are no changes to this section – Use AIAA S-122-2007 verbatim.

### 7.4.3 Bonding of EPS Components to Structure

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 7.5 Wiring and PMP

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 7.6 EPS Worst-Case Analysis

Append the following to the end of Batteries list in AIAA S-122-2007 section 7.6:

- Thermal impacts on cell divergence, impedance, and life

## 7.7 EPS Failure Modes, Effects, and Criticality Analysis (FMECA)

There are no changes to this section – Use AIAA S-122-2007 verbatim.

## 7.8 Contingencies and Margins

There are no changes to this section – Use AIAA S-122-2007 verbatim.

# 8. Bibliography

There are no changes to this section – Use AIAA S-122-2007 verbatim.

AEROSPACE REPORT NO.
TR-RS-2020-00030

# Lithium-Ion Battery Tailoring for AIAA S-122-2007, Electrical Power Systems for Unmanned Spacecraft

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AEROSPACE REPORT NO.
TR-RS-2020-00030

# Lithium-Ion Battery Tailoring for AIAA S-122-2007, Electrical Power Systems for Unmanned Spacecraft

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