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Certification Test Guidance for Small and Medium Sized Rechargeable Lithium Batteries and Battery Systems

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Prepared by: SC-225

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FOREWORD

This report was prepared by Special Committee 225 (SC-225) and approved by the RTCA Program Management Committee (PMC) on December 18, 2013.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal advisory committee and develops consensus-based recommendations on contemporary aviation issues. RTCA's objectives include, but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;

- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;

- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and

- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

The recommendations of RTCA are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration Technical Standard Orders and several advisory circulars.

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EXECUTIVE SUMMARY

RTCA Special Committee SC-225 was formed to develop certification guidance for small and medium sized rechargeable lithium batteries and battery systems.

Members of this committee included representatives from battery and cell manufacturers, avionics manufacturers, aircraft manufacturers, aircraft operators, pilot and flight attendant associations, regulatory and other government agencies, and related industry associations.

The SC-225 committee reviewed and considered regulatory requirements, multiple standards and resources associated with rechargeable lithium batteries in developing this standard. These include FAA Special Conditions related to rechargeable lithium batteries, RTCA/DO-311, UL 1642, UL 2054, UN Section 38.3, and IEC 62133.

1 INTRODUCTION

This document provides design, testing and installation guidance for small (including very small) and medium sized rechargeable lithium batteries and battery systems that are permanently installed on aircraft (see Table 1-1). This document further categorizes battery systems as either Standalone or Embedded.

This section contains safety and design requirements and guidelines as well as quality and other test considerations.

2 QUALIFICATION REQUIREMENTS AND TEST PROCEDURES

This section contains the qualification requirements and test procedures that are performed on rechargeable lithium batteries and battery systems. They include electrical, environmental, and performance requirements and tests.

Testing procedures vary depending on the size of the battery. Some very small batteries are exempted from this standard. A minimum of eight (8) samples are required to perform these tests (see Table 2-2).

3 INSTALLATION CONSIDERATIONS

Basic guidance information is provided to the aircraft installer in this section. This guidance includes the need for a flight crew warning indication (as applicable), a list of some commonly generated hazardous battery emissions, and the importance of reviewing the test data to ensure that the installation design can handle any of the reported results that could have an impact on the aircraft.

The installation should accommodate any venting provisions of the battery or battery system, and must provide containment for electrolyte leakage, toxic gases, and debris. In addition to the guidelines contained within this document, additional lab testing, safety analyses, or on-aircraft testing may need to be performed to demonstrate compliance to the regulatory requirements.

4 GLOSSARY

The Glossary contains a Definition of Terms and a list of Acronyms used in the document.

Appendix A SAFETY GUIDELINES FOR RECHARGEABLE LITHIUM BATTERIES

A summary of the hazards that are associated with rechargeable lithium batteries and the precautions that should be followed when using or handling them are contained in this Appendix.

Appendix B ADDITIONAL REFERENCE MATERIAL

Two matrices comparing the requirements and guidelines in Section 1 to the test procedures in section 2 and the installation considerations in section 3.

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1 INTRODUCTION

Rechargeable lithium batteries, battery systems, and systems with embedded rechargeable lithium batteries (from now on called "batteries and battery systems") of various chemical compositions, sizes, and construction details are being widely promoted for aircraft applications. Among their desirable characteristics are high energy content per unit weight, relatively constant voltage during discharge, the ability to indicate state of charge, and long cycle life. Rechargeable lithium battery systems can provide power throughout the aircraft, including engine or Auxiliary Power Unit (APU) starting, avionics, emergency, and other systems. Because of their high specific energy and potential thermal instability, they can present hazards if improperly designed, tested, used, or stored.

1.1 Purpose

This document provides design, testing, and installation guidance for small[1] and medium sized rechargeable lithium batteries and battery systems that are permanently installed on aircraft. The tests defined in this document also provide a standardized method for characterization of performance of batteries and battery systems.

This document contains certification guidance for batteries and battery systems permanently installed on aircraft. This guidance is provided to the designers and manufacturers of rechargeable lithium batteries and battery systems, aircraft equipment installers, and users within the aviation community. It is the equipment installers responsibility to ensure that the batteries and battery systems meet the certification and installation requirements of the aircraft.

Compliance with these standards is recommended as a means of assuring that the batteries and battery systems will perform their intended function(s) safely under conditions encountered in aeronautical operations. It is imperative that the manufacturer, aeronautical equipment manufacturer, and aircraft manufacturer thoroughly understand the aircraft performance requirements and the capabilities and limitations of the batteries and battery systems to ensure safe operation on the aircraft. Any regulatory application of this document is the responsibility of the applicable government agency.

1.2 References

The following documents contain provisions which, through reference in this text, constitute provisions of this Standard. For all references, the latest edition of the document applies.

IEC 62133 Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications

ISO-9001 Quality management Systems - Requirements

[1] Very small batteries are also included in this standard.

RTCA/DO-160 Environmental Conditions and Test Procedures for Airborne Equipment (latest revision)

RTCA/DO-178 Software Considerations in Airborne Systems and Equipment Certification (latest revision)

RTCA/DO-254 Design Assurance Guidance for Airborne Electronic Hardware (latest revision)

RTCA/DO-311 Minimum Operational Performance Standards for Rechargeable Lithium Batteries and Battery Systems (latest revision)

SAE AS9100 Quality Management Systems - Requirements for Aviation, Space and Defense Organizations

UL 1642 Standard for Safety for Lithium Batteries

UL 2054 Standard for Safety for Household and Commercial Batteries

United Nations Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, Section 38.3 (UN 38.3)

1.3 Scope

This document applies to small and medium sized rechargeable lithium batteries and battery systems that are permanently installed on aircraft. For the purpose of this document, a battery or battery system is considered permanently installed equipment when it is included as part of the type design of the aircraft (or supplemental/amended type design). This standard also applies to rechargeable lithium batteries contained within Portable Electronic Devices (PEDs) that are part of the type design. This document does not apply to primary lithium batteries or large rechargeable lithium batteries or battery systems.

Note: *Rechargeable lithium batteries within PEDs that are not part of the type design are outside the scope of this document; these PEDs fall under the purview of Federal Aviation Administration (FAA) Flight Standards Division and are regulated by operational rules under Title 14 of the Code of Federal Regulations (CFR). PEDs that are not part of the type design, especially those being recharged on the flight deck, present similar hazards as permanently installed equipment.*

1.3.1 Battery and Battery System Size

This standard identifies three sizes of rechargeable lithium batteries and battery systems (see Table 1-1). The Equipment Under Test (EUT) should be identified as to which type it is for determination of applicable test procedures. These categories are used to define applicability of testing per section 2.8.

Table 1–1: Battery Size Classification

Battery Size	Single Cell Battery	Multi Cell Battery	Comments
Very Small	< 2 Wh	< 2 Wh	Includes most button cells.
Small	$2 \leq Wh < 10$	$2 \leq Wh < 50$	
Medium	$10 \leq Wh < 60$	$50 \leq Wh < 300$	Single cells with an energy of 60 Wh or greater, and/or batteries with an energy of 300 Wh or greater are subject to RTCA/DO-311

Note: *Wh is Watt Hours and is defined as the rated capacity (in Ah) times the nominal battery voltage.*

1.3.2 Battery System Types

For the purpose of identification and properly applying the test procedures within this standard, there are two recognized types of battery systems. The system under test should be identified as to which type it is for determination of applicable test procedures.

Standalone: Battery systems that are designed with the primary purpose of providing power to other equipment. These systems are generically referred to as "standalone" battery systems.

Embedded: Battery systems that are designed as part of an integrated system with the primary purpose of providing dedicated power to that system. These systems are generically referred to as "embedded" battery systems.

1.4 General Regulatory Responsibilities

Regulation of equipment installed in aircraft, and component parts of that equipment, are the responsibility of the FAA. In the case of equipment installed in aircraft at the time of manufacture of the aircraft, the aircraft's Type Certificate (TC) specifies the approved aircraft type design including any battery or battery system. Amendments and Supplemental Type Certificates (STC) may be approved subsequent to the original issue of a TC.

The distinction should be noted as to whether equipment containing rechargeable lithium batteries or battery systems are installed as part of the aircraft's equipment or are carried as cargo: in the former case, the FAA has regulatory responsibility, and in the latter case, the Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) has regulatory authority.

1.5 Safety Requirements and Guidelines

Overall, the stated requirements and guidelines contained in this section are generic in nature, and serve only as a baseline for the design and test of specific battery/battery system and equipment pairings.

Proper integration of rechargeable lithium batteries and battery systems into aviation-related equipment requires cooperation between the battery/battery system manufacturer, aircraft designer, and equipment installer. Only through this cooperative exchange of the aircraft performance requirements and the battery's capabilities and limitations can an effective and safe pairing of aircraft, avionics equipment and battery/battery system be realized.

Batteries or battery systems should be designed and tested to the most severe intended operational parameters and operational environment. Excessive charge/discharge rates, temperatures exceeding design limits, improper maintenance, and improper storage may result in dangerous battery failure. Additionally, the safety of the aircraft may be compromised if the battery is not properly sized to provide adequate emergency power for any critical or essential aircraft system.

Below are general requirements pertinent to the safety of rechargeable lithium batteries and battery systems. Safety considerations pertinent to storage, shipping, handling and disposal of rechargeable lithium batteries and battery systems are contained in Appendix A.

1.5.1 Battery Protective Features

The rechargeable lithium battery or battery system shall have protective features to prevent unsafe conditions during operation. The design assurance level of the protective features shall be appropriate for its intended application or installation. Protective circuits should be designed to minimize drain on the battery when it is not in use.

1.5.2 Charging and Discharging Protection

The rechargeable lithium battery system shall be designed to minimize the impact of self-sustained, uncontrolled increases in temperature or pressure, as a result of any foreseeable charging or discharging condition.

Recommended approaches to achieve this design requirement may include any of the following:

- A means to automatically inhibit charging when outside the acceptable voltage or temperature range for any cell.
- A means to automatically inhibit charging when there are any detectable failures of the monitoring system.
- A means to automatically inhibit discharging the battery when outside the acceptable voltage or temperature range for any cell.

- A means to automatically inhibit charging or discharging the battery beyond the cell manufacturer's specified charging and discharging rates.

This requirement only addresses charging and discharging. It does not address internal cell failures (see section 1.5.3).

1.5.3 Mitigation of Cell Failure Effects

The rechargeable lithium battery system shall be designed to minimize the impact of self-sustained, uncontrolled increases in temperature or pressure, as a result of foreseeable cell failures (e.g. internal cell short circuit).

1.5.4 Battery Emissions

The battery system shall not emit any flammable, toxic or corrosive gases, smoke or fluids during normal operation.

Additional information regarding battery emissions during abnormal operation is covered in sections 1.6.2 and 3.1.3.

1.5.5 Flammability

Internal and external materials of the rechargeable lithium battery and battery system shall meet the applicable certification flammability requirements of the installation.

These flammability requirements do not apply to the cell(s). However, any non-metallic material attached to the cell should meet the applicable regulatory flammability requirements of the installation.

Note: *Special consideration should be given to small components that could contribute significantly to the propagation of a fire due to proximity to one or more cells. Therefore, any small part exemption may be inappropriate for materials on or near a cell.*

1.5.6 Instructions for Continued Airworthiness

Each manufacturer shall provide basic information to be used for creating the Instructions for Continued Airworthiness. This information should include, but is not limited to, the following information:

a. Wiring diagram
b. Basic control and operation
c. Installation description
d. Design Life
e. Maintenance Instructions (including capacity check and service interval)
f. Servicing
g. Troubleshooting
h. Removing and Replacing parts
i. Repairs

j. Special Tools, Fixtures and Equipment
k. Component Maintenance Manual
l. Configuration Control Procedures
m. Storage Instructions
n. Airworthiness Limitations
o. Shipping Recommendations/Limitations
p. Disposal

1.5.7 Environmental Qualification

The battery system shall meet the appropriate environmental requirements for the intended application or installation when tested in accordance with RTCA/DO-160 (see section 2.6).

1.6 Design Requirements

The following section provides design requirements for rechargeable lithium batteries and battery systems.

1.6.1 Dissimilar Metals

Where dissimilar metals are used in intimate contact, suitable protection against galvanic corrosion shall be applied.

1.6.2 Venting Provisions

The battery system shall be capable of containing or safely relieving the maximum pressure build-up that can occur under worst case failure conditions as determined by the tests performed in this standard or other known failure conditions. If the battery system is not capable of containing all gases, fluids and/or smoke that can be emitted from the cells, then appropriate venting provisions shall be included. Examples of venting provisions include vent tubes which connect to an aircraft ventilation system, louvers that allow venting from the battery into a ventilated compartment, or vent holes that safely relieve pressure. When venting provisions are included, the vents shall be designed to handle the maximum possible emission rate, temperature, and pressure under all foreseeable environmental conditions. The manufacturer shall provide interface recommendations for the venting system provisions. Emissions shall only escape through designed venting provisions.

1.6.3 Marking

1.6.3.1 Battery Marking

The manufacturer's marking and labeling on the battery exterior shall contain the following minimum information in a legible and durable form:

a. Manufacturer's name or CAGE code

b. Manufacturer's model or part number
c. Manufacturer's serial number and/or date of manufacture
d. Battery Type (e.g. Lithium-Ion or Rechargeable Lithium)

In addition, the following information should be included as applicable.

a. TSO marking
b. Modification numbers or letters
c. Nominal battery or battery system voltage
d. Energy rating in Watt Hours
e. Rated capacity (Ah) (per 2.3.1.1)
f. Battery polarity
g. Weight

Note: *Additional markings may be required as specified in the procurement document or by local regulations.*

1.6.3.2 Cell Marking

All cells shall be clearly and indelibly marked with the following information:

a. Part Number
b. Polarity

In addition, in the case of field replaceable cells, each cell shall be clearly and indelibly marked with the following information:

a. Manufacturer's name or CAGE code
b. Date of manufacture or batch or serial number

Note 1: *Additional markings may be required as specified in the procurement document or by local regulations.*

Note 2: *If the cell is too small or otherwise impractical to mark with any of the information required by this section, the manufacturer may use other means to identify the cell (e.g. bar code, or label on cell packaging).*

1.7 Design Guidelines

The following section provides design guidelines for rechargeable lithium batteries and battery systems.

1.7.1 General Construction

The battery should be manufactured in such a manner as to be uniform in quality and should be free from defects that will affect battery life, functioning, and appearance.

1.7.2 Built-In-Test

Built-In-Test (BIT) should be included in the battery design, as applicable. Rechargeable lithium battery safety is characteristically assured through the implementation of a battery monitoring and management system. These systems are designed to prevent undesirable events such as, over-current, over-charge, over-discharge, over-temperature, etc. Depending on the criticality and reliability of the battery monitoring and management system, the battery and/or battery system design should include a built-in-test function, with the ability to report any detected malfunction or abnormal condition.

1.7.3 Prevention from Bus Back Charging

The battery will be charged on the aircraft by interfacing to a designated source of electrical power. The battery system design should prevent direct charging of the battery from aircraft power buses unless the bus is designed to be the charging source. This could by-pass internal charging controls and result in undesirable charging conditions (bus back charging).

Precautions should also be taken to prevent the battery or battery system from discharging into the input electrical bus of the aircraft which could by-pass internal protections.

1.7.4 Electrical Bonding

For batteries with electrically conductive cases, provision should be made to provide an electrically conductive surface on hold down bars, brackets, or attachment points, for electrical bonding with the airframe as applicable.

1.7.5 Design Review Guidelines

A design review process should be utilized to ensure that the battery will meet all requirements of the application. The following topics should be considered as applicable:

a. Electrical requirements
b. Environmental requirements
c. Battery, battery system, and equipment testing
d. Determine the effect of cell or battery venting with regard to installation
e. Pre-installation bench checks
f. Battery servicing (replacement, repair, inspection)
g. Shipping, storage, handling, and disposal
h. Protective measures
i. Battery system failure or malfunction indication
j. Safety assessment, including safety assessment of battery protective system (FHA, LRU FMEA, SFMEA, FTA)

1.8 Quality

1.8.1 Quality Control and Assurance

The importance of reliability and safety in aircraft applications of rechargeable lithium batteries and battery systems demands an effective quality control system to be followed by the manufacturer.

Quality Assurance is the tool by which the purchaser and manufacturer requirements are satisfied. The manufacturer should have in place an approved quality assurance system. The specific requirements are detailed in an appropriate quality assurance standard such as SAE AS9100, ISO 9000 or other applicable quality standard.

1.8.2 Configuration Control

The manufacturer is required to maintain configuration control of all parts, processes and materials. All configuration changes are to be documented and approved by the appropriate entity.

Change is defined as any modification to approved data such as but not limited to:

a. Drawing lists
b. Outline drawings
c. Manufacturing drawings
d. Master Parts List or Bill of Materials
e. Processes and Specifications
f. Acceptance Test Procedures, Functional Test Requirements, or Test Instruction Sheets Agreement
g. Electronics
h. Software
i. Complex Electronic Hardware
j. Identification Markings
k. Installation Instructions and Limitations
l. Safety Devices
m. Cell design, material or chemistry changes

1.8.3 Workmanship Standards

The battery and battery system shall comply with workmanship standards of the manufacturer. Inspection throughout the manufacturing process should include but may not be limited to:

a. Electrical contact surfaces obstructed by insulation compounds
b. Pitting, blow holes, or burrs on the battery container or cover
c. Electrolyte leakage
d. Location and polarity of terminals not as specified
e. Terminal and identification markings not as specified
f. Evidence of corrosion
g. Particles of foreign material
h. Welds containing blow holes, cracks, or slag inclusions
i. Damage to case, lid and interface connectors

j. Loose parts such as fasteners, connectors, components

1.9 Test Considerations

The test procedures and associated limits specified throughout this document are intended to verify that the requirements contained herein are met.

1.9.1 Test and Verification

The tests imposed upon a rechargeable lithium battery or battery system have as their main consideration safety and performance. However, actual performance of any battery will depend on the specific application. Additional tests and/or analysis may be necessary in the safety assessment process for both the battery and the battery system.

1.9.2 Qualification Tests

Qualification tests demonstrate that the functional, environmental, safety, and performance requirements of a battery or battery system design are met. The tests are to be conducted according to formal procedures, in the order specified in section 2.7, and the results are to be documented.

1.9.3 Operational Tests

Operational tests are not covered in this document. These test procedures and their associated limits are intended to be conducted by equipment maintenance personnel as one means of ensuring that the equipment is functioning properly and can be reliably used for its intended function.

2 QUALIFICATION REQUIREMENTS AND TEST PROCEDURES

2.1 Test Conditions and Apparatus

2.1.1 General Test Conditions

If specific test conditions are not defined for a test, the test shall be carried out under the following general test conditions:

- Absolute air pressure: 84 kPa to 107 kPa (equivalent to +5000 to -1500 ft pressure altitude)
- Ambient Temperature: 23°C ± 5°C
- Relative Humidity (RH): not to exceed 85%

Unless otherwise specified, tests made at conditions other than ambient temperature shall be subject to a tolerance of ± 3°C

For the purposes of this document, temperature stabilization is defined as

- the temperature of a cell at the center of the unit is within 3°C of the specified test temperature, OR
- a minimum of one hour multiplied by the weight of the EUT in kg after the chamber reaches the specified test temperature.

Either method described above shall not be less than 3 hours.

Where specific tolerances have not been defined, a deviation of not more than ± 5% is permitted.

2.1.2 Measuring Apparatus

The measuring method used for the tests shall be selected to suit the magnitude of the parameters to be measured. All test and measurement equipment shall be identified by make, model, serial number and the calibration date where appropriate. The measurement equipment shall be calibrated to the equipment manufacturer's specifications.

2.1.2.1 Current and Voltage Measurement

The current and voltage measurement shall have a minimum accuracy of 0.5%, unless otherwise stated.

2.1.2.2 Temperature Measurement

The temperature measurement shall have a minimum accuracy of 2°C, unless otherwise stated.

2.1.2.3 Additional Test Equipment

All other measurements shall have a minimum measurement accuracy of 5%, unless otherwise stated.

2.1.3 Nominal Voltage

Most aircraft batteries or battery systems utilize voltage values based upon an aircraft electrical system nominally rated at 28 VDC. If the battery or battery system is used for other than the nominal 28 VDC, then the test values shall be adjusted accordingly.

2.1.4 Charging Method

Unless otherwise specified, the battery shall be serviced and charged in accordance with the manufacturer's instructions.

2.2 Physical Examination and Acceptance Test Procedure

The battery or battery system shall be subjected to a physical examination and Acceptance Test Procedure (ATP) as defined in this section.

2.2.1 Physical Examination

Prior to the commencement of the electrical and environmental testing, each EUT being tested shall be inspected as follows to ensure that they comply with the following requirements:

a. Mass and Dimensions per the relevant design documentation.
b. Marking as a minimum as detailed in section 1.6.3.
c. Workmanship standards as detailed in section 1.8.3.

2.2.2 Acceptance Test Procedure

An ATP shall be prepared to verify performance and functionality of the EUT. An ATP shall be run on each sample as specified in section 2.7. An ATP (or a subset) should also be performed to verify EUT operation before and after any test that could impact its intended function. The ATP shall be of sufficient scope to test all system circuit paths and modes of operation required to meet functional requirements. The ATP should also include a visual inspection to ensure that there were no adverse effects on the EUT due to testing.

2.3 Electrical Requirements and Test Procedures

2.3.1 Capacity Testing

2.3.1.1 Rated Capacity Test

Rated Capacity shall be as specified by the manufacturer using one of the three current rates as defined below.

Standalone batteries shall be rated at the I_1 rate. If the battery is not capable of being discharged at the I_1 rate (i.e. I_{Max} is less than I_1), the rated capacity shall be based on the maximum continuous discharge rate (I_{Max}) as declared by the manufacturer.

For embedded batteries, the rated capacity shall be based on I_1, I_{Max} or I_{EUT} (maximum equipment discharge rate). The battery may be removed from the equipment for capacity testing.

2.3.1.1.1 Test Method

a. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

b. Stabilize the EUT at a temperature of 23°C.

c. Discharge the EUT at the I_1 (or I_{Max} or I_{EUT} per 2.3.1.1) rate to its EPV.

2.3.1.1.2 Evaluation Criteria

The battery shall deliver a capacity of not less than 100% of its rated capacity.

2.3.1.2 Constant Current Discharge Test

The Constant Current Discharge Test shall be conducted at both the I_1 and I_{Max} rates at the specified temperatures. If the battery is not capable of being discharged at the I_1 rate, only test at the I_{Max} rate.

For embedded batteries that are rated at the I_{EUT} rate, only run this test at the I_{EUT} rate. For embedded batteries that are rated at I_1 or I_{Max}, the battery may be removed from the equipment for this test.

2.3.1.2.1 Test Method

a. Constant current discharge at -30°C.

   1. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

   2. Stabilize the EUT with no power applied.

3. For batteries with heaters, apply power to the EUT for 15 minutes prior to the start of the discharge period, then remove all power at the start of discharge.

   Note: *Heaters that are powered by the battery are not disabled.*

4. Discharge the EUT at the I_1 (or I_{EUT} per 2.3.1.1) rate to its EPV.

b. Repeat step 2.3.1.2.1.a at -18°C at I_1 or I_{EUT}.

c. Repeat step 2.3.1.2.1.a at +50°C at I_1 or I_{EUT}.

d. Repeat step 2.3.1.2.1.a at -30°C at I_{Max}.

e. Repeat step 2.3.1.2.1.a at -18°C at I_{Max}.

f. Repeat step 2.3.1.2.1.a at +23°C at I_{Max} (not required if 2.3.1.1.1 was conducted at I_{Max}).

g. Repeat step 2.3.1.2.1.a at +50°C at I_{Max}.

Note: For standalone batteries that are not capable of being discharged at the I_1 rate, only steps 2.3.1.2.1.d thru 2.3.1.2.1.g are applicable.

2.3.1.2.2 Evaluation Criteria

The capacity shall be reported and shall not be less than the value stated in the design documentation. The maximum external temperature of the EUT shall be reported for 2.3.1.2.1.c and 2.3.1.2.1.g, as applicable.

2.3.2 Constant Voltage Discharge Test for High Rate Batteries

The purpose of this test is to determine the peak power current (I_{PP}) and the rated power current (I_{PR}). This test is only required on batteries intended for engine starting or other similar high rate applications. Application of external power is not allowed during the temperature stabilization and discharge portions of the test.

2.3.2.1 Test Method

a. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

b. After the EUT is stabilized at a temperature of 23°C, it shall be discharged at a rate so as to maintain a constant terminal voltage corresponding to half the nominal battery voltage for 15 seconds. The discharge load may be adjusted so that the current or voltage limit is not exceeded.

c. Repeat the first two steps using a temperature of -30°C for step 2.3.2.1.b.

d. Repeat the first two steps using a temperature of -18°C for step 2.3.2.1.b.

e. Repeat the first two steps using a temperature of +50°C for step 2.3.2.1.b.

2.3.2.2 Evaluation Criteria

The current at 15 seconds shall be designated I_{PR} and the current at 0.3 seconds shall be designated I_{PP}. The measured I_{PP} and I_{PR} values shall meet or exceed the corresponding ratings specified in the design documentation.

2.3.3 Charge Acceptance Test

The Charge Acceptance Test checks the ability of the battery to accept charge at various temperatures. This assures that energy removed from the battery during ground and start operations can be returned to the battery in a reasonable amount of time so it can provide emergency services.

It also demonstrates that any internal heaters or electronic protection are properly sized and designed. This verifies there will be no irreversible damage to the battery through the application of heater blankets or electronic protection, and that no hazardous conditions will be created by charging at low temperatures.

2.3.3.1 Test Method

a. After the EUT is stabilized at a temperature of 23°C, it shall be discharged at the I_1 (or I_{Max} or I_{EUT} per 2.3.1.1) rate to its EPV.

b. Stabilize the EUT at a temperature of 23°C, then apply external power and charge the EUT for 1 hour in accordance with the manufacturer's instructions for aircraft operation. Record current as a function of time.

   Note: *The battery heater circuit (external or built into the battery system) shall be energized at its specified power during the entire 1.0 h charge.*

c. Remove external power and place the EUT in an ambient temperature environment.

d. Within 5 minutes of removing external power, discharge at the I_1 (or I_{Max} or I_{EUT} per 2.3.1.1) rate to its EPV.

e. Repeat steps 2.3.3.1.a to 2.3.3.1.d using a temperature of -18°C for step 2.3.3.1.b.

f. Repeat steps 2.3.3.1.a to 2.3.3.1.d using a temperature of -30°C for step 2.3.3.1.b.

2.3.3.2 Evaluation Criteria

The charging current as a function of time shall be plotted for a period of 1 hour. The capacity from step 2.3.3.1.d shall be recorded and shall not be less than the value as stated in the design documentation.

2.3.4 Charge Retention Test

WARNING: This test may cause cells to be discharged beyond their safe limit and could pose safety concerns, due to possible fire or explosion, upon subsequent charge/discharge cycles.

This test determines the effect of self discharge by measuring the charge retention after storage at ambient temperature and 50°C for 28 days.

2.3.4.1 Test Method

a. Charge retention at ambient temperature.

   1. Measure and record capacity according to 2.3.1.1.1 (capacity 1).

2. Charge the EUT to 100% State of Charge (SOC) in accordance with the manufacturer's instructions.
3. Store the EUT in an open circuit condition at ambient temperature for a period of 28 days.
4. At the end of the storage period, the EUT shall be stabilized at a temperature of 23°C.
5. Discharge the EUT at the I_1 rate (or I_{Max} rate as applicable) to the EPV and measure and record capacity (capacity 2).

b. Charge retention at 50°C.

1. Repeat the test using a storage temperature of 50°C for step 2.3.4.1.a.3.

2.3.4.2 Evaluation Criteria

The capacities (capacity 1 & 2) and the percent retention of capacity (calculated from capacities 1 & 2) shall be reported for both storage temperatures and shall not be less than the values stated in the design documentation.

2.3.5 Shelf Life Test

WARNING: This test may cause cells to be discharged beyond their safe limit and could pose safety concerns, due to possible fire or explosion, upon subsequent charge/discharge cycles.

The purpose of this test is to determine the effect of long term storage on capacity at ambient and at high temperature.

Completion of the Shelf Life Test is required, but this test is for information only. This test shall be started but not necessarily finished for approval to this standard.

2.3.5.1 Test Method

a. Shelf life at ambient temperature.

1. Charge the EUT to 100% SOC in accordance with the manufacturer's instructions.
2. Measure and record capacity according to 2.3.1.1.1 (capacity 1).
3. Recharge the EUT in accordance with the manufacturer's instructions to the recommended SOC for storage.
4. Store the EUT in accordance with the manufacturer's instructions at ambient temperature for a period of 12 months.
5. At the end of the storage period, the EUT shall be stabilized at a temperature of 23°C.
6. Discharge the EUT at the I_1 rate (or I_{Max} rate as applicable) to the EPV and measure and record the capacity remaining after storage (capacity 2).
7. Recharge the EUT to 100% SOC in accordance with the manufacturer's instructions.

8. Measure and record capacity according to 2.3.1.1.1 (capacity 3).

b. Shelf life at high temperature.

1. Repeat the test using a storage temperature of 38°C (or the manufacturer's maximum recommended storage temperature) for step 2.3.5.1.a.4.

2.3.5.2 Evaluation Criteria

The capacities (capacity 1, 2 & 3) shall be reported for both storage temperatures. Capacity 2 can be used to determine the amount of self-discharge during storage (provided there was no charging during storage). Capacities 1 and 3 can be used to determine the permanent reduction of capacity.

2.3.6 Float Life Test

This test measures the permanent capacity loss when batteries are continuously connected to a power source. This test simulates the normal condition of installed batteries, except the test is run at ambient temperature and at 38°C to accelerate the test time.

Completion of the Float Life Test is required, but this test is for information only. This test shall be started but not necessarily finished for approval to this standard.

2.3.6.1 Test Method

a. Float life at ambient temperature.

1. Charge the EUT to 100% SOC in accordance with the manufacturer's instructions.
2. Measure and record capacity according to 2.3.1.1.1.
3. Recharge the EUT to 100% SOC in accordance with the manufacturer's instructions.
4. Place the EUT in an ambient temperature with the charging circuit connected to the source of charging power.
5. After 90 days, the EUT shall be disconnected from the source of charging power.
6. Measure and record capacity according to 2.3.1.1.1.
7. Recharge the EUT to 100% SOC in accordance with the manufacturer's instructions.
8. Repeat steps 2.3.6.1.a.4 thru 2.3.6.1.a.6 for a total of 360 days or until the capacity at I_1 (or I_{Max}) has declined to 80% of the rated value, whichever occurs first.

b. Float life at 38°C.

1. Repeat the test using a temperature of 38°C for step 2.3.6.1.a.4.

2.3.6.2 Evaluation Criteria

The percent capacity after each 90 day interval and the time to reach 80% of rated capacity shall be reported for both temperatures. If the capacity remains above 80% after 360 days, then only the percent capacity at each 90 day interval shall be reported.

2.3.7 Short-circuit Test of a Cell

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

This test is conducted to show the effects on a battery or battery system when a cell is subjected to a short circuit condition. In the case where cells are connected in parallel, shorting a cell will result in shorting all the parallel connected cells. For batteries or batteries systems that have separate input and output power pins, the input power is connected during this test.

2.3.7.1 Test Method

a. The EUT shall be serviced and charged in accordance with the manufacturer's instructions and stabilized at 55°C.

b. The EUT shall be connected to input power during this test.

c. Subject the terminals of a cell closest to the center of the battery, to a short circuit with a total resistance not to exceed 0.1 ohms.

d. The EUT may be removed from the temperature chamber to avoid contamination of the chamber. If the EUT is removed from the chamber, the short shall be applied prior to the battery dropping below 50°C.

e. Continue to apply the short circuit for at least 1 hour after the external temperature of the EUT has returned to 55°C (or ambient temperature as applicable), then remove the short circuit.

f. Continue to monitor for an additional 3 hours.

g. Throughout the test, record cell voltage, cell current, EUT external temperature, the temperature of the cell being short circuited and the temperature of a cell nearest to the shorted cell (for a multi-cell battery).

Note: *The test sequence should be recorded on video.*

2.3.7.2 Evaluation Criteria

Any of the following constitute a failure:

- Release of debris and/or fragmentation outside of the EUT.
- Escape of flames outside of the EUT.
- Escape of emissions from other than the designed venting provisions.

The following shall also be reported:

- Rupture of the EUT.
- Dimensional distortion outside of specified limits.

- Maximum external temperature of the EUT.
- Emission of smoke, gas, or liquid from the EUT.
- Peak current and last recorded current.
- If the battery becomes open circuit, the time at which the open circuit occurred and the current just prior to the open circuit.

2.3.8 Short-circuit Test with Protection Enabled

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

The Short-Circuit Test with Protection Enabled is conducted to show effectiveness of the protective circuitry when the battery or battery system is subjected to a short circuit condition. The input power is removed to ensure that the source of power is from the battery only. The short circuit test defined below is to be conducted on any and all terminals / connectors capable of delivering the battery's potential energy. Systems that contain an embedded battery without direct connection outside the equipment shall apply the short circuit to the battery subsystem output (including any protective circuitry). For batteries or battery systems with no protective circuitry, this test is satisfied by the Short-circuit Test with Protection Disabled (section 2.3.9), and therefore, this test is not applicable.

2.3.8.1 Test Method

a. All internal or external protective circuits of the EUT shall be fully operational.

b. The EUT shall be serviced and charged in accordance with the manufacturer's instructions and stabilized at 55°C.

c. The EUT shall be disconnected from input power during this test.

d. The power outputs shall then be connected to a short circuit with a total resistance not to exceed 0.1 ohms. For high rate batteries, use a resistance of 2 milliohms instead of 0.1 ohms.

e. For embedded systems, the short circuit shall be applied internally to the terminals/wires of the battery subsystem including any protective circuitry. The battery subsystem shall be installed in the EUT, however the outputs may be disconnected from the remainder of the unit.

f. The EUT may be removed from the temperature chamber to avoid contamination of the chamber. If the EUT is removed from the chamber, the short shall be applied prior to the battery dropping below 50°C.

g. Continue to apply the short circuit for at least 1 hour after the external temperature of the EUT has returned to 55°C (or ambient temperature as applicable), then remove the short circuit.

h. Continue to monitor for an additional 3 hours.

i. Throughout the test, record the output voltage, current, EUT external temperature, and battery temperature.

2.3.8.2 Evaluation Criteria

Any of the following constitute a failure of the protective system:

- Rupture of the EUT.
- Escape of flames outside of the EUT.
- Emission of smoke, gas, or liquid from the EUT.

The following shall also be reported:

- Peak current and last recorded current.
- If the battery becomes open circuit, the time at which the open circuit occurred and the current just prior to the open circuit.
- Maximum external temperature of the EUT.

2.3.9 Short-circuit Test with Protection Disabled

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

This test is to determine the effects of an external short circuit when there is no short circuit protection or when the short circuit protection has failed. This test provides information on the maximum anticipated output current. The input power is removed to ensure that the source of power is from the battery only. This test shall be performed on all batteries or battery systems whether or not they incorporate protective circuits.

2.3.9.1 Test Method

a. All protective devices shall be disabled except fuses and fusible links. Protective devices that are incorporated within the cell(s) do not need to be disabled.

b. The EUT shall be serviced and charged in accordance with the manufacturer's instructions and stabilized at 55°C.

c. The EUT shall be disconnected from input power during this test.

d. The power outputs shall then be connected to a short circuit with a total resistance not to exceed 0.1 ohms. For high rate batteries, use a resistance of 2 milliohms instead of 0.1 ohms.

e. For embedded systems, the short circuit shall be applied internally to the terminals/wires of the battery subsystem excluding any protective circuitry. The battery subsystem shall be installed in the EUT, however the outputs may be disconnected from the remainder of the unit.

f. The EUT may be removed from the temperature chamber to avoid contamination of the chamber. If the EUT is removed from the chamber, the short shall be applied prior to the battery dropping below 50°C.

g. Continue to apply the short circuit for at least 1 hour after the external temperature of the EUT has returned to 55°C (or ambient temperature as applicable), then remove the short circuit.

h. Continue to monitor for an additional 3 hours.

i. Throughout the test, record the output voltage, current, EUT external temperature, and battery temperature.

Note: *The test sequence should be recorded on video.*

2.3.9.2 Evaluation Criteria

Any of the following constitute a failure:

- Release of debris and/or fragmentation outside of the EUT.
- Escape of flames outside of the EUT.
- Escape of emissions from other than the designed venting provisions.

The following shall also be reported:

- Deformation of the EUT.
- Maximum external temperature of the EUT.
- Emission of smoke, gas, or liquid from the EUT.
- Peak current and last recorded current.
- If the battery becomes open circuit, the time at which the open circuit occurred and the current just prior to the open circuit.
- Any protective devices that were not disabled.

2.3.10 Insulation Resistance Test

This test measures the resistance to current leakage from power circuits through insulating materials used in the battery. Excessive leakage current can cause excessive self-discharge of battery cells, disturb the operation of high impedance circuits, and lead to deterioration of the insulation by heating.

2.3.10.1 Test Method

a. Apply a potential of 250VDC +/- 10% for 60 +5/-0 seconds to the following test points at the electrical connector(s) of the EUT: If the applied DC potential could cause damage to sensitive electronic components, it may be reduced to a value of twice the nominal battery voltage (+/-10%).

   1. Between each mutually isolated electrical power contact (for multiple power inputs or multiple power outputs).

   2. Between each electrical power contact and an electrically conductive portion of the case.

   Note: *If the EUT has a non-metallic case or the case is common with power ground, step 2.3.10.1.a.2 is not required.*

2.3.10.2 Evaluation Criteria

The value of the insulation resistance at the 60 second mark shall not be less than 10 Mega ohms. After environmental testing, as defined in section 2.6, the value of the insulation resistance at the 60 second mark shall not be less than 2 Mega ohms.

2.3.11 Duty Cycle Performance Test for High Rate Batteries

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

The purpose of this test is to simulate repetitive engine or APU starts to determine the ability of the battery to perform its intended function and be re-charged for a preset number of cycles. This test is only required on batteries intended for engine starting or other similar high rate applications.

2.3.11.1 Test Method

The following test shall be performed at ambient temperature. Cooling that is not part of the battery or battery system design is not allowed.

a. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

b. A duty cycle consists of the following sequence:

   1. The EUT shall be discharged through a fixed resistive load for 20 seconds. The value of the resistive load (in ohms) shall be equal to 2.5 times the nominal battery voltage divided by its rated value of I_{PR} or as declared in the design documentation.

   2. After standing on open circuit for 2 minutes it shall again be discharged through the resistive load for 20 seconds.

   3. The EUT shall then be charged in accordance with the manufacturer's instructions for a maximum of 60 minutes.

   4. The EUT shall then stand on open circuit for not more than 2 hours.

c. The duty cycle (steps 2.3.10.1.a.1 to 2.3.10.1.a.4) shall be repeated 50 times unless otherwise specified in the design documentation. If the battery charging or discharging is inhibited due to the EUT thermal protective circuits, the battery shall be allowed to cool enough to allow continued cycling.

d. The EUT shall be immediately discharged at the I_1 rate, recording the duration to its EPV.

e. Measure and record capacity according to 2.3.1.1.1.

f. Repeat steps 2.3.10.1.b thru 2.3.10.1.e above to provide a minimum total of 100 duty cycles.

g. Throughout the test, record the EUT external temperature and battery temperature.

2.3.11.2 Evaluation Criteria

Any of the following constitute a failure:

- Rupture of the EUT.
- Escape of flames outside of the EUT.
- Emission of smoke, gas, or liquid from the EUT.
- Minimum battery terminal voltage less than 55% of nominal battery voltage (i.e. 13 volts for a nominal 24 volt battery) during all discharges.

- Measured capacity in step 2.3.11.1.e less than 54 minutes (90% of C_1).
- Dimensional distortion outside of specified limits.

The following shall also be reported:

- Maximum external temperature of the EUT.
- Capacity measured in step 2.3.11.1.e.
- The duration of any shut-down(s) due to the EUT thermal protective circuits.

2.3.12 Deep Discharge Test

WARNING: This test may cause cells to be discharged beyond their safe limit and could pose safety concerns, due to possible fire or explosion, upon subsequent charge/discharge cycles.

The Deep Discharge Test establishes the performance of the battery and its ability to recover from a deep discharge.

Note: *Protective functions of the EUT should be operational for this test.*

2.3.12.1 Test Method for Standalone Batteries

a. Measure and record capacity according to 2.3.1.1.1 (capacity 1).

b. Apply a 1 ohms ±10% resistor (or the minimum resistance needed to prevent overcurrent tripping) between the positive and negative terminals of the discharged EUT. The resistor shall remain connected for two weeks at ambient temperature.

c. Remove the resistor circuit and leave the EUT to stand in the discharged condition for a further two weeks.

d. Measure and record capacity according to 2.3.1.1.1 (capacity 2).

2.3.12.2 Test Method for Embedded Batteries

a. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

b. Disconnect the EUT from external power and ensure the EUT is on and powered from the battery.

c. Measure the time it takes for the EUT to exhaust the battery (capacity 1).

d. Leave the EUT to stand in the discharged condition for a further two weeks.

e. Repeat steps 2.3.12.2.a thru 2.3.12.2.c (capacity 2).

2.3.12.3 Evaluation Criteria

The battery shall have passed this test if capacity 2 is greater than or equal to 90% of capacity 1 (or the percent value as stated in the design documentation).

However, if the battery is designed to prevent recharge after deep discharge, capacity 2 is not applicable. Under this circumstance, the battery shall be considered to have passed if

it prevents recharge. For this condition, report the time duration after the measurement of capacity 1 until the battery prevents recharge.

2.3.13 Overcharge Test with Protection Enabled

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

The Overcharge Test with Protection Enabled is conducted to show effectiveness of the protective circuitry of the battery or battery system when the battery is overcharged at 1.5 times the rated nominal battery voltage. The temperature of the battery shall be measured on a cell near the center of the battery.

The protective system shall prevent the battery from going into thermal runaway. This verifies correct operation of the battery protective system.

2.3.13.1 Test Method

a. All internal or external protective circuits of the EUT shall be fully operational.

b. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

c. Connect the inputs of the protective circuit (see point A on Figure 2-1) to a power supply set to the following:

   1. constant voltage of 1.5 times the rated nominal battery voltage.

   2. current limit of 8 times the I_1 (or I_{Max} if less than I_1) current of the battery.

d. The power supply shall not be removed until:

   1. the charge current does not change by more than 5% I_1 (or I_{Max} if there is no I_1 rating) over a 60 minute period, and

   2. the battery temperature does not increase by more than 5°C over a 60 minute period.

e. After the power supply is removed, monitor the EUT until the battery temperature is at ambient.

f. Throughout the test, record the applied voltage, charging current, EUT external temperature, and battery temperature.

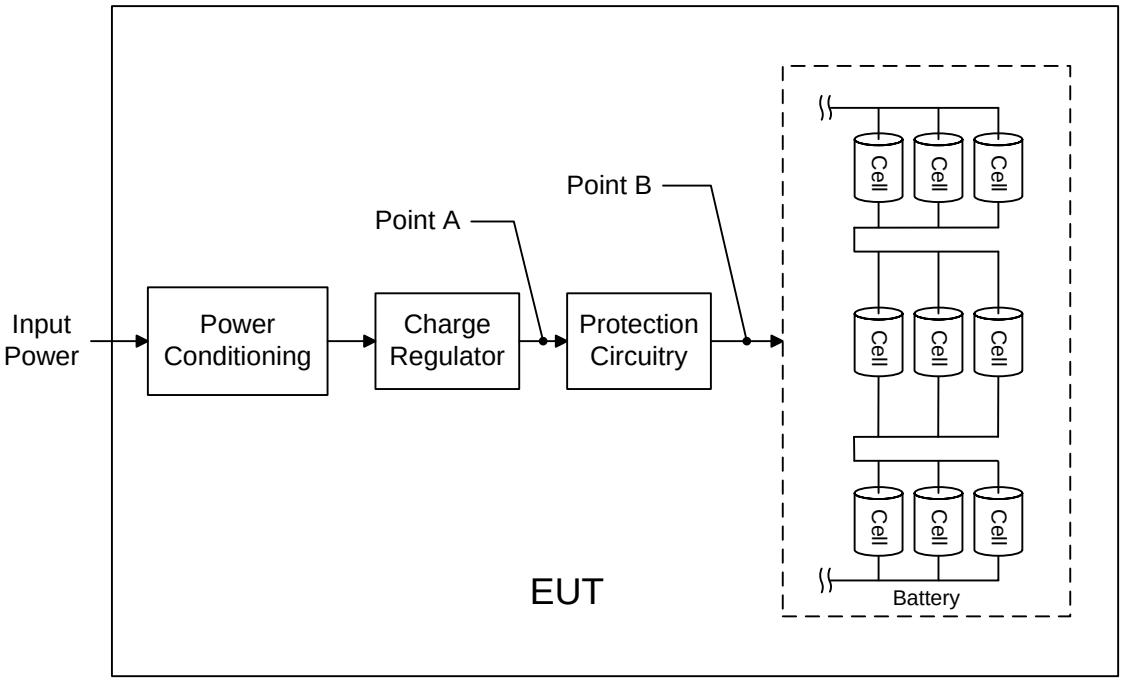

Figure 2–1: Internal Test Points for Overcharge Testing

Note: *This figure is a generic representation of battery system design. The specific test points may vary depending on the specific design of the EUT.*

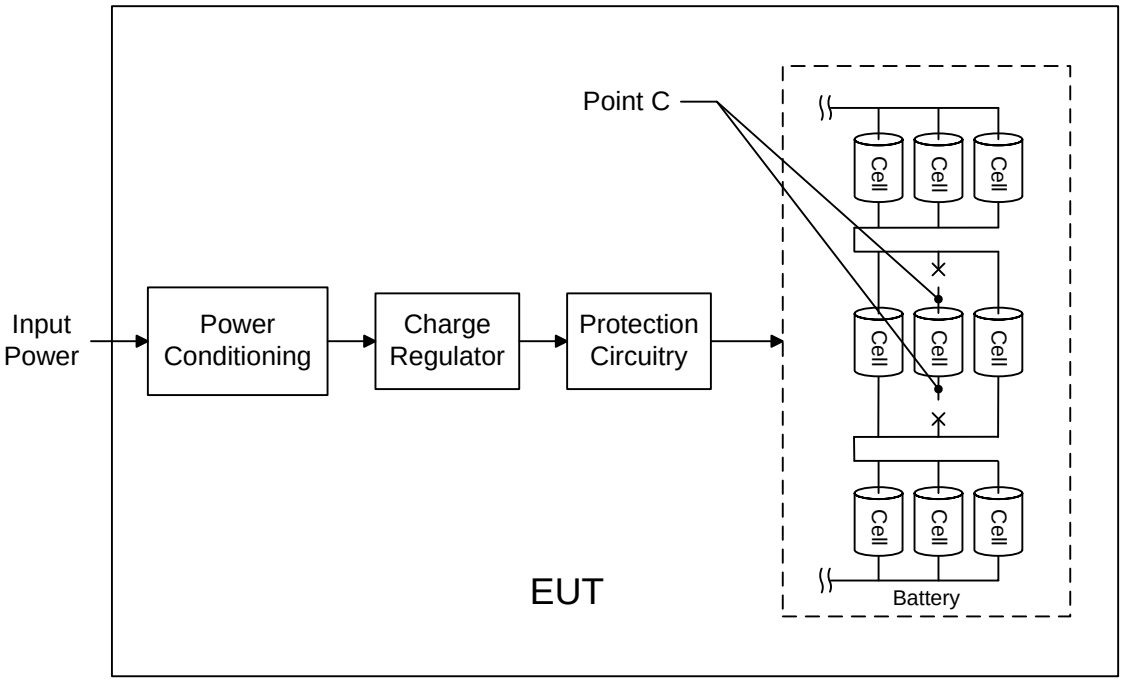

Figure 2–2: Internal Test Points for Thermal Runaway Testing

Note: *This figure is a generic representation of battery system design. The specific test points may vary depending on the specific design of the EUT.*

2.3.13.2 Evaluation Criteria

Any of the following constitute a failure of the protective system:

- Rupture of the EUT.
- Escape of flames outside of the EUT.
- Emission of smoke, gas, or liquid from the EUT.

The following shall also be reported:

- Peak current and last recorded current.
- If the battery becomes open circuit, the time at which the open circuit occurred and the current just prior to the open circuit.
- Maximum battery temperature.
- Maximum external temperature of the EUT.
- The physical condition of the battery and EUT after the test.

2.3.14 Overcharge Test with Protection Disabled

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

The Overcharge Test with Protection Disabled is conducted to determine the effects of an unprotected overcharge of the battery, which could potentially result in a thermal run-away condition. The temperature of a cell near the center of the battery shall be measured during this test.

2.3.14.1 Test Method

a. All protective devices shall be disabled except fuses and fusible links. Protective devices that are incorporated within the cell(s) do not need to be disabled.

b. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

c. Connect the inputs of the battery sub-system (see point B on Figure 2-1) to a power supply set to the following:

   1. constant voltage of 1.5 times the rated nominal battery voltage.

   2. current limit of 8 times the I_1 (or I_{Max} if less than I_1) current of the battery.

d. The power supply shall not be removed until:

   1. the charge current does not change by more than 5% I_1 (or I_{Max} if there is no I_1 rating) over a 60 minute period, and

   2. the battery temperature does not increase by more than 5°C over a 60 minute period.

e. After the power supply is removed, monitor the EUT until the battery temperature is at ambient.

f. Throughout the test, record the applied voltage, charging current, EUT external temperature, and battery temperature.

g. The entire test sequence shall be recorded on video and retained with the test data.

2.3.14.2 Evaluation Criteria

Any of the following constitute a failure:

- Release of debris and/or fragmentation outside of the EUT.
- Escape of flames outside of the EUT.
- Escape of emissions from other than the designed venting provisions.

The following shall also be reported:

- Rupture of the EUT.
- Escape of flames outside of the EUT.
- Emission of smoke, gas, or liquid from the EUT.
- Maximum battery temperature.
- Maximum external temperature of the EUT.
- Any protective devices that were not disabled.

2.3.15 Thermal Runaway Containment Test

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

This test is conducted to determine the effectiveness of the case to contain the resulting effects of a thermal runaway. These effects could include the explosion of a cell or the ignition of vapors and/or electrolyte in the battery or battery system that might occur if a cell were to fail. This test is intended to simulate a failure due to a defective cell.

2.3.15.1 Test Method

a. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

b. Prepare the EUT with an ignition source (e.g. a spark at a minimum of twice every second, a glow plug or a heated wire) inside the battery case. The energy of the ignition source shall be sufficient to ignite natural gas.

c. Induce a thermal runaway in an cell closest to the center of the battery by connecting the terminals of a single electrically isolated cell (see point C on Figure 2-2) to a power supply set to the following:

   1. constant voltage of at least 1.5 times the rated nominal cell voltage.
   2. current limit of 8 times the I_1 (or I_{Max} if less than I_1) current for a single cell.

d. The power supply shall not be removed until:

   1. the charge current does not change by more than 5% I_1 (or I_{Max} if there is no I_1 rating) over a 60 minute period, and
   2. the external EUT temperature does not change by more than 5°C over a 60 minute period.

e. If the cell does not enter thermal runaway in step 2.3.15.1.c, an additional test shall be conducted on a separate battery. Repeat steps 2.3.15.1.a and 2.3.15.1.b. A heating device sufficient to cause thermal runaway shall be applied to a cell closest to the center of the battery.

f. The power to the heating device shall not be removed until the external EUT temperature does not change by more than 5°C over a 60 minute period.

Note: *With current chemistries, thermal runaway will typically occur before the cell case reaches 300°C. New chemistries may require higher temperatures to produce thermal runaway.*

g. Continue to monitor the EUT for steps 2.3.15.1.c and 2.3.15.1.d, or 2.3.15.1.e and 2.3.15.1.f, as applicable, until the battery temperature is at ambient.

h. Throughout the test, record the applied voltage, charging current, EUT external temperature, the temperature of the cell being heated and the temperature of a cell nearest to the heated cell (for a multi-cell battery).

Note: *The test sequence should be recorded on video.*

2.3.15.2 Evaluation Criteria

Any of the following constitute a failure:

- Release of debris and/or fragmentation outside of the EUT.
- Escape of flames outside of the EUT.
- Escape of emissions from other than the designed venting provisions.

The following shall also be reported:

- Emission of smoke, gas, or liquid from the EUT.
- Rupture of the EUT.
- Maximum external temperature of the EUT.

2.4 Physical Requirements

2.4.1 Handle Strength Test

The Handle Strength test is conducted to assure that the handle(s) function(s) properly (only when handle(s) are present).

2.4.1.1 Test Method

Each EUT handle shall be subjected to a tension load of 2 times the EUT weight. The tension shall be applied in a vertical upward direction.

2.4.1.2 Evaluation Criteria

There shall be no damage to the EUT including evidence of breaking, bending or cracking.

2.4.2 Drop Impact Test

WARNING: Exercise extreme caution when carrying out this test to prevent injury due to the potential of explosion or fire.

The Drop Impact Test is only required for installed equipment which includes a portable device containing a rechargeable lithium battery that is intended to be handled and used during aircraft operations.

This test is performed to ensure that the portable portion of the installed equipment will remain safe to personnel during handling in the aircraft.

2.4.2.1 Test Method

a. The EUT shall be serviced and charged in accordance with the manufacturer's instructions.

b. Drop the EUT from a height of 1 m (3.28 ft) so it strikes a concrete surface so as to obtain impacts in random orientations. The EUT is to be dropped three times.

c. Charge the EUT using the intended charging source.

d. Monitor the EUT for 6 hours.

2.4.2.2 Evaluation Criteria

Any of the following constitute a failure:

- Escape of flames outside of the EUT.
- Emission of smoke, gas, or liquid from the EUT.

The following shall also be reported:

- The external physical condition of EUT after the test.

2.5 Software and Hardware Requirements

2.5.1 Software

If the battery system includes software, it shall be developed according to document RTCA/DO-178, *Software Considerations in Airborne Systems and Equipment Certification*. The RTCA/DO-178 software level shall be consistent with the failure condition classification.

2.5.2 Hardware

If the battery system contains complex electronic hardware, it shall comply with RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*. The RTCA/DO-254 hardware level shall be consistent with the failure condition classification.

2.6 Environmental Qualification Requirements

The battery or battery system shall be tested to the applicable sections of RTCA/DO-160, *Environmental Conditions and Test Procedures for Airborne Equipment*.

The test sections and test categories shall be selected commensurate with the intended installation location and the appropriate hazard classification of the battery or battery system.

For tests which require the EUT to be operating, the most susceptible operating mode or modes shall be used.

Any of the following which occur during or following these tests constitute a failure:

- Release of debris and/or fragmentation outside of the EUT.
- Rupture of the EUT.
- Escape of flames outside of the EUT.
- Emission of smoke, gas, or liquid from the EUT.
- Deformation of the EUT beyond the specified tolerance limits, corrosion, or physical damage.
- Loss of integrity of EUT venting provisions.

The following shall also be reported:

- Any irregular variation of output voltage or current.

Table 2–1: Environmental Tests

Test	Environmental Condition	DO-160 Section	Remarks
4a	Temperature	§4.5	Required
4b	Altitude	§4.6.1	Required
4c	Decompression & Overpressure	§4.6.2-§4.6.3	As Applicable
5	Temperature Variation	§5	Required
6	Humidity	§6	Required
7a	Operational Shock	§7.2	Required
7b	Crash Safety	§7.3	Required See Note below
8	Vibration	§8	Required
9	Explosion Proofness	§9	As Applicable
10	Waterproofness	§10	As Applicable
11	Fluids Susceptibility	§11	As Applicable
12	Sand and Dust	§12	As Applicable
13	Fungus Resistance	§13	As Applicable
14	Salt Fog	§14	As Applicable
15	Magnetic Effect	§15	As Applicable
16	Power Input	§16	Required
17	Voltage Spike	§17	Required
18	Audio Freq. Conducted Susceptibility	§18	Required
19	Induced Signal Susceptibility	§19	Required
20	RF Susceptibility	§20	Required
21	Emission of RF Energy	§21	Required
22	Lightning Induced Transient Susceptibility	§22	Required
23	Lightning Direct Effects	§23	As Applicable
24	Icing	§24	As Applicable
25	Electrostatic Discharge	§25	Required
26	Fire / Flammability	§26	As Applicable

Notes:

1. *"As Applicable" in the above table means when necessary to support installation issues and is not specifically required by this standard.*

2. *For crash safety (Test 7b), the EUT does not have to be operational after the test. Test T.4 of UN 38.3 may be substituted for Crash Safety testing, if the EUT was tested using the intended mounting provisions of the EUT.*

2.7 Order of Testing

A minimum of nine samples shall be used for approval testing. Additional samples may be used in accordance with the notes of Table 2-2. The battery system and test hardware shall be maintained under configuration control. The order of testing for each sample shall be from top to bottom as given in Table 2-2.

Completion of the Shelf Life Test (2.3.5) and the Float Life Test (2.3.6) is required, but these tests are for information only.

For samples I, II, III, IV, and IX perform an ATP just prior to performing the destructive tests (2.3.7, 2.3.9, 2.3.14, 2.3.15, 2.4.2). For the remaining samples, perform an ATP at the completion of all testing.

Table 2–2: Test Matrix

Test	Section	Footnote	Sample Number								
			I	II	III	IV	V	VI	VII	VIII	IX
Physical Examination	2.2.1	1	X	X	X	X	X	X	X	X	X
Insulation Resistance	2.3.10	1	X	X	X	X	X	X	X	X	X
Rated Capacity	2.3.1.1	1	X	X	X	X	X	X	X	X	X
Constant Current Discharge	2.3.1.2		X	X	X						
Constant Voltage Discharge	2.3.2		X	X	X						
Charge Acceptance	2.3.3	2									
Charge Retention	2.3.4	2, 6									
Short-circuit with Protection Enabled	2.3.8	2									
Duty cycle performance	2.3.11	2									
Deep Discharge	2.3.12	2									
Overcharge with Protection Enabled	2.3.13	2									
Handle Strength	2.4.1	2									
DO-160 Environmental Tests	2.6	3									
Insulation Resistance	2.3.10	4									
ATP	2.2.2		X	X	X	X					X
Short-circuit of a Cell	2.3.7	5	X								
Short-circuit with Protection Disabled	2.3.9	5		X							
Overcharge with Protection Disabled	2.3.14	5			X						
Thermal Runaway Containment	2.3.15	5				X					
Shelf Life - Sample 1	2.3.5						X				
Shelf Life - Sample 2	2.3.5							X			
Float Life - Sample 1	2.3.6								X		
Float Life - Sample 2	2.3.6									X	
Drop Impact	2.4.2	5									X
ATP	2.2.2						X	X	X	X	

Footnotes:

1. These tests shall be performed in the order specified.

2. *These tests shall be run on at least one sample, and may be run in any order and on any sample.*
3. *The DO-160 tests may be run on any number of samples and in any order, unless otherwise specified in DO-160.*
4. *This test shall be run on each DO-160 test article, after DO-160 testing has been completed.*
5. *This test is expected to be a destructive test.*
6. *Testing at 23°C and 50°C may be run on two different samples.*

2.8 Applicable Tests Based on Battery Size

Battery size is defined in Table 1-1.

Medium batteries shall be tested to all of the requirements of Table 2-2.

Small batteries shall be tested to all of the requirements of Table 2-2, with the exception of following tests:

2.3.2 Constant Voltage Discharge for High Rate Batteries
2.3.11 Duty Cycle Performance for High Rate Batteries
2.4.1 Handle Strength

Very Small batteries are exempted from the testing requirements of this standard if they have met the requirements of UL 1642, UL 2054, or IEC 62133. Otherwise, they shall be tested to the requirements for Small batteries.

Note: *Battery testing standards for UL, International Electrotechnical Commission (IEC), and United Nations (UN) are not a substitute for the testing requirements of this document for small and medium sized batteries.*

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3 INSTALLATION CONSIDERATIONS

3.1 Equipment Installation

This section contains installation considerations that may impact the design of the battery and battery system. It also provides guidance to the installer of this equipment.

3.1.1 Warning System

Any aircraft that uses a rechargeable lithium battery or battery system whose function is necessary for safe operation may require the incorporation of a monitoring and warning feature that will provide an accurate indication to the appropriate flight crewmembers whenever the state-of-charge of the batteries has fallen below levels considered acceptable for dispatch of the aircraft.

3.1.2 Aircraft Environment

The rechargeable lithium battery or battery system should be compatible with the environmental conditions present in the specific location of the aircraft where the equipment is installed. These environmental conditions include, but are not limited to, temperature, altitude, humidity, vibration, waterproofness, and Electromagnetic Interference (EMI).

3.1.3 Hazardous Battery Emissions

Many rechargeable lithium batteries contain hazardous materials. Under abusive conditions such as overcharge, heating, or internal cell shorting, additional hazardous materials, many in the gas phase, may be generated. Hazardous emitted gases may include, but are not limited to:

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- n-Butane (C_4H_{10})
- Diethyl carbonate ($C_5H_{10}O_3$)
- Dimethyl carbonate ($C_3H_6O_3$)
- Ethane (C_2H_6)
- Ethyl fluoride (C_2H_5F)
- Ethylene (C_2H_4)
- Ethylene carbonate ($C_3H_4O_3$)
- Ethyl-methyl carbonate ($C_4H_8O_3$)
- Hydrogen (H_2)
- Hydrogen fluoride (HF)
- Methane (CH_4)
- Oxygen (O_2)
- Propane (C_3H_8)
- Propylene (C_3H_6)
- Propylene carbonate ($C_4H_6O_3$)

These gases may be flammable, explosive, corrosive, or toxic in certain concentrations. The installer should work with the manufacturer to quantify and mitigate the emissions of hazardous gases. One method to mitigate this risk is by implementing venting provisions (see section 1.6.2).

3.1.4 Impact on Installation Design

There are some tests in this standard that provide information beyond the pass/fail criteria, which is pertinent for installation considerations. Therefore, the installer should review the test data and any associated video recordings of the battery or battery system, to ensure that the installation design can mitigate any of the reported results that could have an impact on the aircraft.

3.1.5 Additional Equipment Installation Considerations

- Accommodate any venting provisions on the battery or battery system as applicable.
- Provide containment of electrolyte leakage, toxic or explosive gases, and debris as applicable.
- Provide thermal cooling (convection, forced air, glycol, etc.) as applicable.

3.2 Safety Considerations for Installed Equipment

Functional Hazard Classifications (Minor, Major, Hazardous, Catastrophic) are assessed at the aircraft level. Different category and classes of aircraft require different levels of failure mitigation appropriate to the aircraft. Various installation approval guidance may be applicable to determining the aircraft level failure classifications and the appropriate level of mitigation at the aircraft level. Equipment Design Assurance Levels (DAL) are used together with other mitigation techniques appropriate to the function, such as redundancy, to appropriately mitigate failures of the battery or battery system function at the aircraft level. Equipment Designers should consider the type of aircraft in which the equipment may be installed, the criticality associated with failures of the function, and possible or required aircraft-level mitigations appropriate to that type of aircraft when choosing equipment DAL.

Safety Analysis, such as a FHA, or a Failure Modes and Effects Analysis (FMEA), may need to be conducted as required by the appropriate regulatory requirements in order to meet the equipment installation DAL.

3.3 Test Procedures for Installed Equipment

Qualification testing in a laboratory is not always sufficient to demonstrate compliance to the regulatory requirements of the installation. Tests for the installed equipment are required when performance cannot be adequately determined through laboratory testing. Installed Equipment tests are normally performed under two conditions:

1. With the aircraft on the ground and using simulated or operational system inputs.
2. With the aircraft in flight using operational system inputs appropriate to the equipment under test.

Ground and flight testing may be used to demonstrate functional performance in the intended operational environment. This testing may also be used to demonstrate non-interference to other systems due to electromagnetic effects.

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4 GLOSSARY

4.1 Definition of Terms

For the purpose of this standard, the following definitions apply.

Airworthiness
Is defined as the compliance of a battery or part thereof with all conditions and regulations required by the appropriate Government authorities for their safe operation and performance in an airborne environment.

Ampere-hour
A unit for the quantity of electrical capacity obtained by integrating current in amperes over time in hours. Used as a measure of battery capacity (abbreviated Ah).

Battery
One or more electrically connected cells, assembled in a single container having positive and negative terminals. A battery may include inter-cell connectors and protective and other devices.

Battery System
Is comprised of the battery, the battery charger and any protective, monitoring and alerting circuitry or hardware inside or outside of the battery. It also includes vents (where necessary) and packaging.

Button Cell
A button cell is a round cell where the overall height is less than the diameter.

Cell
A single electrochemical unit which exhibits a voltage across its two terminals and is used as a component of a battery.

Charge Retention
The fraction of the full capacity available from a battery under specified conditions of discharge after it has been stored for a specific period of time at a specified temperature.

Charged Battery
A battery that has been fully charged in accordance with the manufacturer's instructions or as defined in the design documentation.

Charging Current
Current provided to a cell or battery in the direction opposite the flow of current during discharge.

Constant Voltage Discharge
Performed to determine the maximum power capability of the battery. This information is used for proper sizing of aircraft electrical systems.

Deep Discharge
Withdraw of at least 80% of the rated capacity of a cell or battery.

Discharge
The operation of a cell or battery in providing electrical current to an external load.

Distortion
The change in any dimension of a cell or battery beyond the design tolerances.

Electrolyte
A medium in which the transport of electrical charge in a cell takes place by the migration of ions between the positive and negative electrodes.

Embedded Battery System
See section 1.3.2.

End Point Voltage (EPV)
End Point Voltage is the voltage at which the discharge of the battery or battery system should be discontinued to prevent over discharge.

Equipment Under Test (EUT)
Equipment Under Test (can be cells, batteries, or LRUs with embedded cells or batteries). This is the article being qualified to this standard.

High Rate Battery
A battery or battery system that is rated to provide a peak power current (I_{PP}) greater than $10I_1$. Any battery used for engine or APU start is also considered a high rate battery.

I_1 Rate
The current is that which the battery delivers to give not less than its rated C_1 capacity to the EPV in 1 hour. This shall be the basis on which all other current ratings are defined.

I_{EUT} Rate
The maximum discharge rate of the equipment under test. This only applies to embedded systems.

I_{Max} Rate
The maximum continuous current, as declared by the manufacturer, that the battery is capable of delivering to the EPV.

I_{PP} - Peak Power Current
The discharge current, which the battery delivers at the conclusion of a 0.3 second power discharge, controlled so as to maintain a constant terminal voltage of half the nominal battery voltage.

I_{PR} - Rated Power Current
The discharge current, which the battery delivers at the conclusion of a 15 second power discharge, controlled so as to maintain a constant terminal voltage of half the nominal battery voltage.

Leakage
Release of liquid or gas from a cell or battery. Leakage is determined by either visual observation or weight loss.

Load

An electrical load is any circuit which causes current flow when connected to the terminals of a cell or battery.

Manufacturer

The entity who produces or supplies the rechargeable lithium battery or battery system.

Nominal Battery Voltage

Nominal battery voltage is the nominal cell voltage (as specified by the manufacturer) multiplied by the number of cells in series.

Overcharge

Overcharge is the forcing of current through a cell or battery after all the active material has been converted to the charged state. In other words, charging is continued after 100% state of charge is achieved.

Protective Circuits

Protective Circuits are any component or circuit external to the cell, that are used to protect the cell(s) or battery from failures. Protective circuits may consist of active or passive devices, or both. Active devices may include field effect transistors, relays, contactors, and circuit breakers. Passive devices may include fuses, fusible links, and positive temperature coefficient devices.

Rated Capacity (C_1, C_{Max}, or C_{EUT})

The minimum capacity, expressed in Ah, obtained from a charged battery when discharged at the I_1, I_{Max} or I_{EUT} rate to the End Point Voltage (see section 2.3.1.1).

Rupture

Rupture includes splitting, cracking or bursting of the case.

Serviced

A battery that has been fully prepared and maintained in accordance with the manufacturer's instructions or as defined in the design documentation.

Shelf Life

The maximum period at which an un-discharged cell or battery stored under standard conditions retains 80 percent of rated ampere-hour capacity. The manufacturer specifies shelf life.

Short Circuit

A direct connection between the terminals of a cell or battery that provides a near-zero resistance path for current flow. An internal short circuit is a defect or fault within a cell, which causes the anode and cathode to come into electrical contact.

Specific Energy

The energy per unit weight expressed as Wh/kg.

Standalone Battery System

See section 1.3.2.

State of Charge (SOC)

An indication of the capacity remaining in a battery compared to its fully charged

condition. It is usually expressed as a percentage value (0% to 100%). For rechargeable lithium batteries it is typically determined from one of two methods – voltage measurement or current integration (coulomb counter).

Thermal Runaway
Thermal runaway is defined as an uncontrolled increase in temperature or pressure.

Vent
A design feature of a cell or battery which activates to relieve excessive internal pressure.

Venting
Release of liquid or gas from a cell designed to prevent the buildup of excessive internal pressure. Observation and weight loss are indicators of venting.

Watt Hours (Wh)
The rated capacity (Ah) times the nominal battery voltage.

4.2 Acronyms

Ah	Ampere-hour (see 4.1)
APU	Auxiliary Power Unit
ATP	Acceptance Test Procedure
BIT	Built-in-test
CFR	Code of Federal Regulations
CAGE	Commercial And Government Entity
DAL	Design Assurance Level
DOT	Department of Transportation
EMI	Electromagnetic Interference
EPV	End Point Voltage (see 4.1)
EUT	Equipment Under Test (see 4.1)
FAA	Federal Aviation Administration
FHA	Functional Hazard Assessment
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis
IEC	International Electrotechnical Commission
LRU	Line Replaceable Unit

PED	Portable Electronic Device
PHMSA	Pipeline and Hazardous Materials Safety Administration
PMC	Program Management Committee
RH	Relative Humidity
SDS	Safety Data Sheet
SFMEA	System Failure Modes and Effects Analysis
SOC	State of Charge (see 4.1)
STC	Supplemental Type Certificates
TC	Type Certificate
TSO	Technical Standard Order
UL	Underwriters Laboratories
UN	United Nations
Wh	Watt Hour (see 4.1)

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5 MEMBERSHIP

RTCA Special Committee 225

Rechargeable Lithium Batteries and Battery Systems

Chairman	Organization
Richard Nguyen	The Boeing Company
Secretary	**Organization**
Stephen Diehl	The Boeing Company
RTCA Program Director	**Organization**
Jennifer Iversen	RTCA, Inc.

Member	Organization
Alfonso Abalos	Panasonic Avionics Corporation
Jonathan Alon	Bombardier Aerospace
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Remi Andreoletti	Zodiac Aerospace
George Au	U.S. Army
Chris Baker	ACME Aerospace
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Julie Banner	NSWG Carderock
Mehdy Barekatein	The Boeing Company
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Avijit Bhunia	Teledyne Controls Division
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Mori Borumand	The Boeing Company
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Rich Byczek	Intertek Testing Services NA
Joe Castaldo	Aeroflex Plainview
Vernon Chang	Cessna Aircraft Company
Guillaume Cherouvrier	Zodiac Aerospace
James Christo	NASA
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David Correia	Federal Aviation Administration
Earl Cox	AeroVironment
Rebecca Davis	EaglePicher Technologies LLC
Wellington de Macedo	EMBRAER

Fabricio de Oliveria Spigolon	EMBRAER
Cathleen DeLoach	National Fire Protection Association
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Holland Guldberg	Universal Avionics Systems Corp.
Alex Haynes	DME Corporation
Ann Heinke	Overlook Consulting, Inc.
Paul Hollett	Concorde Battery Corporation
Richard Hopf	BAE Systems Controls
Jose Jacobi	EMBRAER
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Michael Johnson	Federal Aviation Administration
Rand Johnson	Crane Aerospace & Electronics
Jeff Jouper	Astronics AES
Derek Kaczmarek	Intertek Testing Services NA
George Kerchner	PRBA - The Rechargeable Battery Association
Richard Kessel	Air Line Pilots Association
Nazih Khaouly	Federal Aviation Administration
Scott Lichte	EnerSys
Roger Lin	A123Systems Inc.
Bob Luetkemeyer	American Airlines, Inc.
Mark Lukso	Panacis
Larry Masters	Gulfstream Aerospace Corporation
Janet McCaughlin	Federal Aviation Administration
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Jessie Turner	The Boeing Company
Brian Verna	Federal Aviation Administration
David Vutetakis	Concorde Battery Corporation
Michael Waller	Saft America, Inc.
Harry Webster	Federal Aviation Administration
Brett Williams	Mid-Continental Instruments
Tae Yoon	Honda Aircraft Company, Inc.
Guenter Zellmer	Airbus Americas, Inc.

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A APPENDIX A: SAFETY GUIDELINES FOR RECHARGEABLE LITHIUM BATTERIES

This appendix provides a concise summary of the safety hazards associated with rechargeable lithium batteries and precautions that should be followed when using or handling them. All personnel who use or handle rechargeable lithium batteries should be familiar with this information.

A.1 Electric Burn Hazard

Rechargeable lithium batteries are capable of delivering high currents if the terminals are shorted. The resulting heat can cause severe burns and is a potential fire hazard. Take the following precautions:

- Do not place tools or metal objects across battery terminals.
- Do not wear conductive rings, belt buckles, watches or other jewelry when handling batteries.
- Wear insulated gloves and use insulated tools when handling batteries.
- Install battery terminal protectors whenever the battery is not connected in the aircraft or to the test equipment.

A.2 Electric Shock Hazard

Rechargeable lithium batteries rated at 50 volts or above are capable of delivering a lethal shock to personnel. These batteries are required to be placarded to indicate the electrical shock hazard. Take the following precautions:

- Wear insulated gloves and use insulated tools when handling or servicing batteries.
- Install battery terminal protectors whenever the battery is not connected in the aircraft or to the test equipment.

A.3 Thermal Runaway

Thermal runaway is a condition in which the battery temperature or pressure increases rapidly resulting in extreme overheating of the battery and excessive pressures inside the cell(s). When thermal runaway occurs, the battery can melt, release hazardous gases, catch on fire, emit sparks, or even explode. Causes of thermal runaway include a) exposure of battery to extreme temperatures; b) mechanical abuse of battery such as dropping, puncturing, or crushing; c) improper charging or discharging procedures when servicing; d) failure of electronic protection devices/circuits; and e) defective cells. Take the following precautions:

- Do not heat or incinerate battery.
- Use special care when handling batteries. Make sure they are not dropped, punctured, crushed or otherwise mutilated.
- Wear proper hand, eye and face protection when handling batteries.
- Make sure work area is well ventilated.
- Do not service batteries in the vicinity of other combustible material.
- Charge and test batteries only in accordance with manufacturer’s recommendations.

- If thermal runaway does occur, follow instructions on manufacturer's Safety Data Sheet (SDS).

A.4 Damage to Connectors

To prevent damage to electrical connectors such as arc burns or melted contacts, batteries should never be connected or disconnected while being charged or discharged. Batteries should be connected or disconnected only when the circuit is open. Ensure the aircraft battery switch, external power source, or the charger/analyzer is in the "OFF" position before connecting or disconnecting the battery. Battery terminal protectors should be installed whenever the battery is not connected in the aircraft or to the test equipment.

A.5 Storage

Rechargeable lithium batteries should be stored in a dry and well-ventilated area and should not normally be kept in the same area as flammable materials. Humidity or temperature control is not necessary in most instances but for maximum shelf life the temperature should between -20ºC and 30ºC. Exposure to temperatures above 50ºC should be kept to a few days in any year. Storage temperatures above 60ºC should be avoided.

Proper battery storage depends on the battery chemistry, users should consult the manufacturer for proper battery storage.

A.6 Shipping

The transport as cargo of rechargeable lithium batteries is regulated (including when shipped by an air carrier on its own aircraft as company material (COMAT)). The appropriate transport regulations of each country should be consulted before transporting rechargeable lithium batteries. In the U.S., these regulations are found in 49 CFR Parts 100-185.

A.7 Disposal

Proper disposal of rechargeable lithium batteries is a matter of concern to battery producers, users and governmental bodies. The battery SDS should be consulted for relevant disposal information. Batteries should be recycled or sent to the manufacturer for recycling in accordance with all applicable Federal, State, and Local regulations for the particular battery being used.

A.8 Mixing of Cells or Batteries

Mixing cells or batteries with different part numbers, made by different manufacturers, or from different sources, is not an acceptable practice. Cells or batteries may have different capacities and voltage characteristics, because they have different designs, manufacturing processes or storage, use or age histories. Cells or batteries of different capacities in series connection may result in the lower capacity battery(ies) being driven into a

detrimental deep discharge (forced discharge) or overcharge. Refer to the manufacturers maintenance manuals for proper servicing of each manufacturer's battery system.

A.9 Battery Polarity

Installing one or more batteries incorrectly, with the battery output terminals reversed, will result in the reversed battery being charged by others in the circuit during discharge and discharged by the charging system during charge. This may also result in injury to installer.

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B APPENDIX B: ADDITIONAL REFERENCE MATERIAL

Section	2 Qualification Requirements and Test Procedures	2.1 Test Conditions and Apparatus	2.1.1 General Test Conditions	2.1.2 Measuring Apparatus	2.1.2.1 Current and Voltage Measurement	2.1.2.2 Temperature Measurement	2.1.2.3 Additional Test Equipment	2.1.3 Nominal Voltage	2.1.4 Charging Method	2.2 Physical Examination and Acceptance Test Procedure	2.2.1 Physical Examination	2.2.2 Acceptance Test Procedure	2.3 Electrical Requirements an Test Procedures	2.3.1 Capacity Testing	2.3.1.1 Rated Capacity Test	2.3.1.2 Constant Current Discharge Test	2.3.2 Constant Voltage Discharge Test for High Rate Batteries	2.3.3 Charge Acceptance Test	2.3.4 Charge Retention Test	2.3.5 Shelf Life Test	2.3.6 Float Life Test	2.3.7 Short-circuit Test of a Cell	2.3.8 Short-circuit Test with Protection Enabled	2.3.9 Short-circuit Test with Protection Disabled	2.3.10 Insulation Resistance Test	2.3.11 Duty Cycle Performance Test for High Rate Batteries	2.3.12 Deep Discharge Test	2.3.13 Overcharge Test with Protection Enabled	2.3.14 Overcharge Test with Protection Disabled	2.3.15 Thermal Runaway Containment Test	2.4 Physical Requirements	2.4.1 Handle Strength Test	2.4.2 Drop Impact Test	2.5 Software and Hardware Requirements	2.5.1 Software	2.5.2 Hardware	2.6 Environmental Qualification Requirements	2.7 Order of Testing	2.8 Applicable Tests Based on Battery Size
1.5 Safety Requirements and Guidelines																																							
1.5.1 Battery Protective Features												X						X	X	X		X	X	X		X	X	X	X	X				X	X	X		
1.5.2 Charging and Discharging Protection												X						X				X	X	X		X	X	X	X	X						X		
1.5.3 Mitigation of Cell Failure Effects																						X								X								
1.5.4 Battery Emissions																						X	X	X		X		X	X	X			X			X		
1.5.5 Flammability																																				X		
1.5.6 Instructions for Continued Airworthiness																			X	X	X																	
1.5.7 Environmental Qualification																																				X		
1.6 Design Requirements																																						
1.6.1 Venting Provisions																						X	X	X		X		X	X	X						X		
1.6.2 Marking																																						
1.6.2.1 Battery Marking											X																											
1.6.2.2 Cell Marking											X																											
1.7 Design Guidelines																																						
1.7.1 General Construction											X																											
1.7.2 Built-In-Test												X																								X	X		
1.7.3 Prevention from Bus Back Charging									X			X																								X	X		
1.7.4 Electrical Bonding																																					X		
1.7.5 Dissimilar Metals																									X											X		
1.7.6 Design Review Guidelines																																				X	X		

Figure B–1: Cross Reference Matrix between Requirements and Guidelines (Section 1) to Test Procedures (Section 2)

Section	3 INSTALLATION CONSIDERATIONS	3.1 Equipment Installation	3.1.1 Warning System	3.1.2 Aircraft Environment	3.1.3 Hazardous Battery Emissions	3.1.4 Impact on Installation Design	3.1.5 Additional Equipment Installation Considerations	3.2 Safety Considerations for Installed Equipment	3.3 Test Procedures for Installed Equipment
1.5 Safety Requirements and Guidelines									
1.5.1 Battery Protective Features			X				X	X	X
1.5.2 Charging and Discharging Protection									
1.5.3 Mitigation of Cell Failure Effects									
1.5.4 Battery Emissions					X				
1.5.5 Flammability									
1.5.6 Instructions for Continued Airworthiness									
1.5.7 Environmental Qualification				X					
1.6 Design Requirements									
1.6.1 Venting Provisions					X		X		
1.6.2 Marking									
1.6.2.1 Battery Marking									
1.6.2.2 Cell Marking									
1.7 Design Guidelines									
1.7.1 General Construction									
1.7.2 Built-In-Test								X	
1.7.3 Prevention from Bus Back Charging									
1.7.4 Electrical Bonding									
1.7.5 Dissimilar Metals									
1.7.6 Design Review Guidelines									

Figure B–2: Cross Reference Matrix between Requirements and Guidelines (Section 1) to Installation Considerations (Section 3)