



AEROSPACE STANDARD	AS6413™	
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Performance-Based Package Standard for Lithium-Ion Cylindrical Cells
as Cargo on Aircraft

RATIONALE

The fire protection capabilities and certification of original equipment manufacturers' (OEMs) airframes and systems were developed considering the carriage of general cargo and not the unique hazards associated with the carriage of dangerous goods, including lithium batteries. The Council of the International Civil Aviation Organization (ICAO) established a prohibition on the transport of lithium batteries as cargo on passenger aircraft as a temporary measure until controls were put into place that establish an acceptable level of safety. The SAE G27 committee was established at the request of ICAO to develop a package performance standard for lithium cells and batteries, UN3090 and UN3480, as cargo in air transportation.

TABLE OF CONTENTS

1.	SCOPE.....	3
2.	REFERENCES.....	3
2.1	Applicable Documents	3
2.1.1	SAE Publications.....	3
2.1.2	IEC Publications.....	3
2.2	Related Publications	3
2.2.1	ICAO Publications.....	3
2.2.2	United Nations Publications.....	4
2.3	Definitions	4
3.	PACKAGE PERFORMANCE REQUIREMENTS	5
3.1	Containment of Thermal Runaway Products and Effects	5
3.2	List of Tests.....	6
4.	TESTING HAZARDS	6
4.1	Safety of Laboratory Personnel	6
4.2	Hazardous Gas Considerations	6
5.	INTERNAL CELL THERMAL RUNAWAY: CELLS IN SPECIFIC PACKAGING TEST	6
5.1	Purpose	7
5.2	Test Article	7
5.2.1	Preparation of Test Article	7
5.3	Test Procedure.....	9
5.3.1	Criteria to Allow Monitoring Outside the Test Chamber.....	13
5.4	Pass/Fail Criteria.....	14

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6.	CRITERIA FOR EVALUATION OF CHANGES TO A TESTED PACKAGE BY SIMILARITY ANALYSIS.....	16
6.1	Mandatory Test Required	16
6.2	Cell Changes.....	16
6.3	Packaging Changes.....	16
6.4	Package Changes.....	17
6.5	Any analysis must include the documentation required by 7.4.....	17
7.	DOCUMENTATION	17
7.1	Summary Report Sheet.....	17
7.2	Detailed Test Report	18
7.3	Package Configuration Instructions for Transport	20
7.4	Components of a Changed Package Qualification by Similarity Analysis	20
8.	NOTES.....	20
8.1	Revision Indicator.....	20
APPENDIX A	EQUIPMENT AND CALIBRATION	21
Figure 1	Example of positioning the initiation cell (represented by the red cell).....	8
Figure 2	Example placement of the test article in the test chamber showing the overhead central location of the spark igniter and the side-mounted circulation fan	10
Figure 3	Test chamber right side view	11
Figure 4	Test chamber front view.....	12
Figure 5	Test chamber top view	12
Figure 6	Surface temperature limit example (see Figures 7 and 8 for expansion).....	14
Figure 7	Example cell temperature excursion during thermal runaway, with the allowable 150 °C rise in surface temperature	15
Figure 8	Expanded Figure 6 for surface temperature	15

1. SCOPE

This SAE Aerospace Standard (AS) specifies the testing requirements, including test equipment, to demonstrate a package of lithium-ion (UN3480) cylindrical cells of a format of 21700 or smaller intended for air transport contains the potential hazardous effects to the aircraft resulting from the failure of a cell within the package.

The test described in this standard is intended to force a cylindrical lithium-ion cell into thermal runaway using thermal energy applied to the exterior of a cell. It is understood that, in the future, technology may be developed that will prevent cells from going into thermal runaway by this standard's test protocol. The scope of this standard may be expanded as more technology and information become available.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6840 Performance-Based Package Standard for Lithium Batteries as Cargo on Aircraft, Background Information and Rationales

2.1.2 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61960-3 Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells for portable applications - Part 3: Prismatic and cylindrical lithium secondary cells made from them

IEC 62133-2 Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary lithium cells, and for batteries made from them, for use in portable applications - Part 2: lithium systems

IEC 62620 Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications

IEC 62660-1 Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 ICAO Publications

Available from International Civil Aviation Organization, 999 University Street, Montreal, Quebec H3C 5H7, Canada, Tel: +1 514-954-8219, <http://www.icao.int/>.

Doc 9284 Technical Instructions for the Safe Transport of Dangerous Goods by Air

2.2.2 United Nations Publications

Available from United Nations Economic Commission for Europe, Palais des Nations, CH-1211, Geneva 10, Switzerland, Tel: +41-0-22-917-12-34, www.unece.org.

Recommendations on the Transport of Dangerous Goods - Model Regulations

Recommendations on the Transport of Dangerous Goods - Manual of Tests and Criteria

2.3 Definitions

2.3.1 Reserved

2.3.2 Reserved

2.3.3 Reserved

2.3.4 CELL

A single encased electrochemical unit (one positive and one negative electrode) that exhibits a voltage differential across its two terminals and may contain protective devices.

2.3.5 CYLINDRICAL CELL

A cell with a circular cross section and a height that is greater than the diameter.

2.3.6 Reserved

2.3.7 Reserved

2.3.8 INITIATION CELL

A single cell to which an initiation source and thermocouples have been attached to monitor the heating rate and thermal runaway status. The location of the initiation cell is chosen as described in 5.2.1.

2.3.9 INITIATION SOURCE

A thermal source used to initiate thermal runaway in a cell.

2.3.10 Reserved

2.3.11 PACKAGE

The complete product of the packing operation, consisting of the packaging and its contents, including cells, as presented for transport.

2.3.12 PACKAGE CONFIGURATION INSTRUCTIONS

Documentation providing descriptions of the package components and assembly of the components to reproduce conditions conforming to this performance standard.

2.3.13 PACKAGING

One or more receptacles and any other components or materials necessary for the receptacles to perform their containment and other safety functions.

2.3.14 PERIPHERY ZONE

A row of live cells within a test article surrounding the propagation zone in all applicable X, Y, and Z directions. The periphery zone is used to demonstrate that the thermal runaway propagation between cells stops in the propagation zone.

2.3.15 PROPAGATION OF THERMAL RUNAWAY

Transfer of heat energy from a cell experiencing thermal runaway that results in thermal runaway in one or more adjacent cells.

2.3.16 PROPAGATION ZONE

Area defined within a test article where propagation of thermal runaway between cells is allowed during testing.

2.3.17 STATE OF CHARGE (SOC)

For the purposes of performing this test, the residual electrical capacity remaining in the cell expressed as a percentage of the rated capacity.

2.3.18 SUB-PACKAGE

A discrete, repeatable, independent configuration of cells and packaging that can be transported within a package that has its own physical boundary. The physical boundary is not required to be the package as presented for transport.

2.3.19 Reserved

2.3.20 SURROGATE CELL

An object that supports the same transport of heat as a cell but does not add energy to the test. For example, an electrically and chemically inert object having similar form, volume, heat capacity, and thermal conductivity as the cells that may be used for testing in place of a cell is a surrogate cell.

2.3.21 TEST ARTICLE

A specific package or a sub-package as prepared for transport, modified as required to accomplish the test.

2.3.22 THERMAL RUNAWAY

The initiation of an irreversible exothermic chemical reaction within the cell causing an uncontrollable release of internal electrical and chemical energy, resulting in a rapid and accelerating rise of temperature.

2.3.23 VENTING

Release of excessive internal pressure from a cell in a manner intended by design to preclude rupture or disassembly.

3. PACKAGE PERFORMANCE REQUIREMENTS

3.1 Containment of Thermal Runaway Products and Effects

NOTE: These are the high-level performance requirements that are the basis of this test standard. The specific test pass/fail criteria to prove these performance requirements are provided in 5.4.

- 3.1.1 The package shall contain the initial thermal runaway and the consequences of the thermal runaway in order to assist the aircraft fire control systems for the remainder of the flight.
- 3.1.2 No flames or fragments exiting the package that could ignite surrounding material.
- 3.1.3 No surface temperatures on the package that could ignite surrounding material.
- 3.1.4 No gases released that, if ignited, could result in a pressure pulse affecting the aircraft cargo compartment.

3.2 List of Tests

- 3.2.1 Internal cell thermal runaway: cells in specific packaging (see Section 5).

4. TESTING HAZARDS

These tests are designed to severely abuse a single cell such that it enters thermal runaway with the presumption that a single cell may enter thermal runaway during transport. These test procedures describe methods to evaluate the combined capability of the cell and packaging to limit the consequences of a single cell in thermal runaway from becoming hazardous.

4.1 Safety of Laboratory Personnel

The responsible test organization and all organizations involved in conducting tests outlined in this standard are cautioned that many of the tests and conditions may result in hazardous conditions both during the test and with the test article following the test. Proper care should be taken to protect personnel and property during and after the test. For example, discharging or stabilizing the energy remaining in the cell assembly may be appropriate prior to dismantling, storage, or disposal. If appropriate, cell assembly external surface temperatures may be monitored and test personnel advised to avoid direct contact with the test article until the cell assembly has reached ambient temperatures. In some instances, hazardous conditions may not be evident until an extended period of time has passed, and caution shall be exercised while storing tested cells. The responsible test organization involved in conducting tests is encouraged to consult with the applicable cell manufacturer to gain an understanding of the cell technical specifications and any unique hazards associated with conducting tests.

4.2 Hazardous Gas Considerations

Under certain severe failure conditions, lithium-based cells can emit gases that may be harmful to humans in sufficient concentrations. Examples may include, but are not limited to, carbon monoxide (CO), carbon dioxide (CO₂), and hydrogen fluoride (HF). Consideration should be given to preventing the buildup of these gases in sufficient concentration to be harmful inside the test facility.

The responsible test organization should determine what a harmful concentration may be based on accepted industry practice or standards. Examples of industry standards include Emergency Response Planning Guidelines, available from the American Industrial Hygiene Association; Permissible Exposure Limits or Short-Term Exposure Limits, available from the Occupational Safety and Health Administration (OSHA); Acute Exposure Guideline levels, available from the Environmental Protection Agency (EPA); Recommended Exposure Limits, available from the National Institute for Occupational Safety and Health (NIOSH); or Threshold Limit Values, available from the American Conference of Governmental Industrial Hygienists (ACGIH).

Under certain failure conditions, lithium-based cells also can emit gases that may be flammable in air in appropriate concentrations. Examples may include organic electrolyte vapors, methane, ethane, or hydrogen gas. Consideration should be given to preventing the buildup of flammable gases and avoiding flammable gas contact with known ignition sources outside of the test chamber.

5. INTERNAL CELL THERMAL RUNAWAY: CELLS IN SPECIFIC PACKAGING TEST

Successful completion of three consecutive tests using the same test procedure and acceptance criteria is required. See Appendix A for additional requirements and information.

5.1 Purpose

This test describes the method to evaluate the combined capability of the cell and packaging to limit the consequences of a single cell in thermal runaway from becoming hazardous. The test is conducted on a package or a sub-package containing lithium rechargeable cells at a specified state of charge (SOC) and as prepared for air transport, modified as required to accomplish the test and gather the required data.

5.2 Test Article

A package may be tested using cells in all available locations or by using a lesser number of cells than the package is designed and intended to contain. At a minimum, cells are required to be present in a propagation zone and a periphery zone. (For an example, refer to Section 3 of AIR 6840.)

When using a lesser number of cells, additional preparation and data measurement is required, including determining the propagation zone and periphery zone prior to the test. Surrogate cells may be used for cells located beyond the periphery zone. When using a surrogate cell, it shall have the following properties:

1. Greater or equal volume of air displacement.
2. Heat capacity and thermal conductivity that are less than or equal to the missing cells. Examples include:
 - a. A discharged cell of the type being tested.
 - b. A surrogate cell for an 18650 cell could be an aluminum cylinder with a cross section of 18-mm diameter and length of 65 mm, with a 4.2-mm hole drilled down the axis.

5.2.1 Preparation of Test Article

1. The cells shall be prepared for test such that each cell SOC shall be at 110% of the maximum SOC that the cells will be presented for transport. However, cells transported at an SOC greater than 90% shall be tested fully charged.

EXAMPLE: At 50% SOC of rechargeable cells as presented for transport, 110% means 55% SOC for testing those cells in the test article; i.e., $30\% \text{ (SOC as presented for transport)} + (10\% \text{ of } 30\%) = 33\% \text{ (SOC as tested in the test article)}$ or $70\% \text{ (SOC as presented for transport)} + (10\% \text{ of } 70\%) = 77\% \text{ (SOC as tested in the test article)}$.

2. The SOC of the cells shall be verified prior to test.

NOTE: The determination of SOC should be based on the manufacturer's method, one of the following methods, or another standard method:

Method 1: Provided a detailed look-up table is available for the cell, then the SOC may be determined by establishing the open circuit voltage of the cell and using this value to establish the SOC.

Method 2: The procedures defined in IEC 61960-3, IEC 62133-2, IEC 62660-1, or IEC 62620 may be used to determine the capacity of the cell using the end point voltage declared by the manufacturer. The determined capacity shall be used as the reference capacity for establishing the SOC using a method for the applicable cell.

3. The voltage of the cells shall be checked and recorded during preparation of the test article.
4. Place the initiation source in contact with the initiation cell. Apply insulation only over the heater outer surface. Do not apply insulation to the remainder of the cell surface. This will minimize the heat source effect to the packaging and not impede the heat transport from the initiation cell to the other cells.

5. Either:
 - a. Where it is planned to conduct the entire 5-hour observation period, connect thermocouples to the initiation cell in the location most representative of the cell's internal temperature
 - b. Where it is intended to conduct the initial test in the test chamber and then remove the test article from the test chamber without a 5-hour observation period, connect thermocouples to the initiation cell in the location most representative of the cell's internal temperature and all adjacent cells.
6. For most cylindrical cells, the most representative and accessible place to measure the temperature is on the external surface of the cell approximately 1 to 3 mm from a side edge of the heat source along the vertical centerline of the cell.
7. Reassemble the packaging with the cells in the test article as they would be if presented for transport.
 - i. The initiation cell shall be located to maximize the heat transfer from the initiation cell to an adjacent cell and determine if propagation to additional cells will happen.
 - ii. In the case of a single row or a single row with only one layer of cells, the initiation cell shall be closest to the middle of the row adjacent to the test article wall as shown in the middle layer of Figure 1.
 - iii. In the case of multiple layers of rows of cells, it is likely that the best location for the initiation cell will be nearest to the center and closest to the test article wall (see Figure 1).

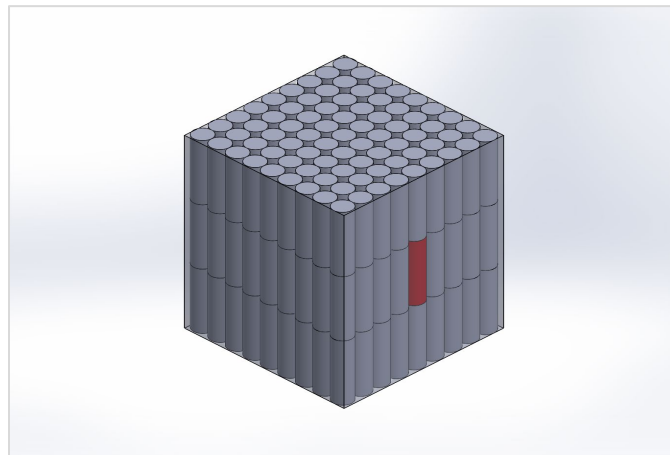


Figure 1 - Example of positioning the initiation cell (represented by the red cell)

- iv. The initiation cell shall be oriented such that the insulated heat source faces the outer package surface. Test equipment accessories (leads, etc.) shall be installed to have the minimum impact on the test. Wires should exit through a corner that is opposite the side with the initiation cell.
- v. The test article, prior to being closed, must be conditioned for at least 24 hours at a temperature of $21\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$, with a relative humidity of $50\% \pm 5\%$. After this period, the test article can be closed for testing. The opening or gap around the wires should be closed.
- vi. If the cells have special (different) conditioning requirements as a part of the test article as prepared for transport, they must be prepared/conditioned according to those package instructions.
- vii. Seal the package using the materials and processes as required to be presented for transport.

8. Place one thermocouple on the external test article surface next to the initiation cell as close to the initiation cell as possible. A thermocouple shall be placed as close to the center of each remaining face of the external test article surface as possible. Do not place thermocouples on materials that could potentially affect proper temperature readings. A minimum of one thermocouple is required for each outside face of the test article, excluding the bottom. External surface thermocouples shall be covered by a thermally insulating pad (i.e., 2.5 cm by 2.5 cm) to prevent excess cooling by the active airflow and allow accurate measurement of heat emerging through the wall material.

NOTE: The objective of the placement of the thermocouples is to be able to confidently measure the temperature in enough areas on the outer surface of the test article in order to have a high degree of confidence that the highest temperature can be recorded during the test. For irregularly shaped test articles, additional thermocouples may be required beyond one per face of the test article to ensure that the intent of this section is accomplished. The external thermocouples shall remain in contact with the test article for the duration of the test. High-temperature tape, polyimide tape, or equivalent performance tape may be used. Otherwise, pressure from the bending moment of a thermocouple sheathing may provide sufficient contact.

5.3 Test Procedure

- a. The test chamber functional parameters (including the free volume) and calibration as identified in Appendix A shall be completed before starting this test procedure.
- b. Record all information required for documentation as per Section 7.
- c. The conditioned test article shall be placed in the test chamber. The test article shall be placed such that the test article surface is completely on the insulation on the floor of the chamber but no less than 50 mm from any other surface of the chamber (see Figure 2). The method for verification of no hazardous flames or fragments shall be selected and mounted as appropriate as described in A.1.1.3 or A.1.1.4.
- d. The temperature of the test chamber, ambient air, and test article shall be between 15 to 30 °C (59 to 86 °F) at the start of the test. The ambient lab temperature shall be maintained at 15 to 30 °C (59 to 86 °F) throughout the test.

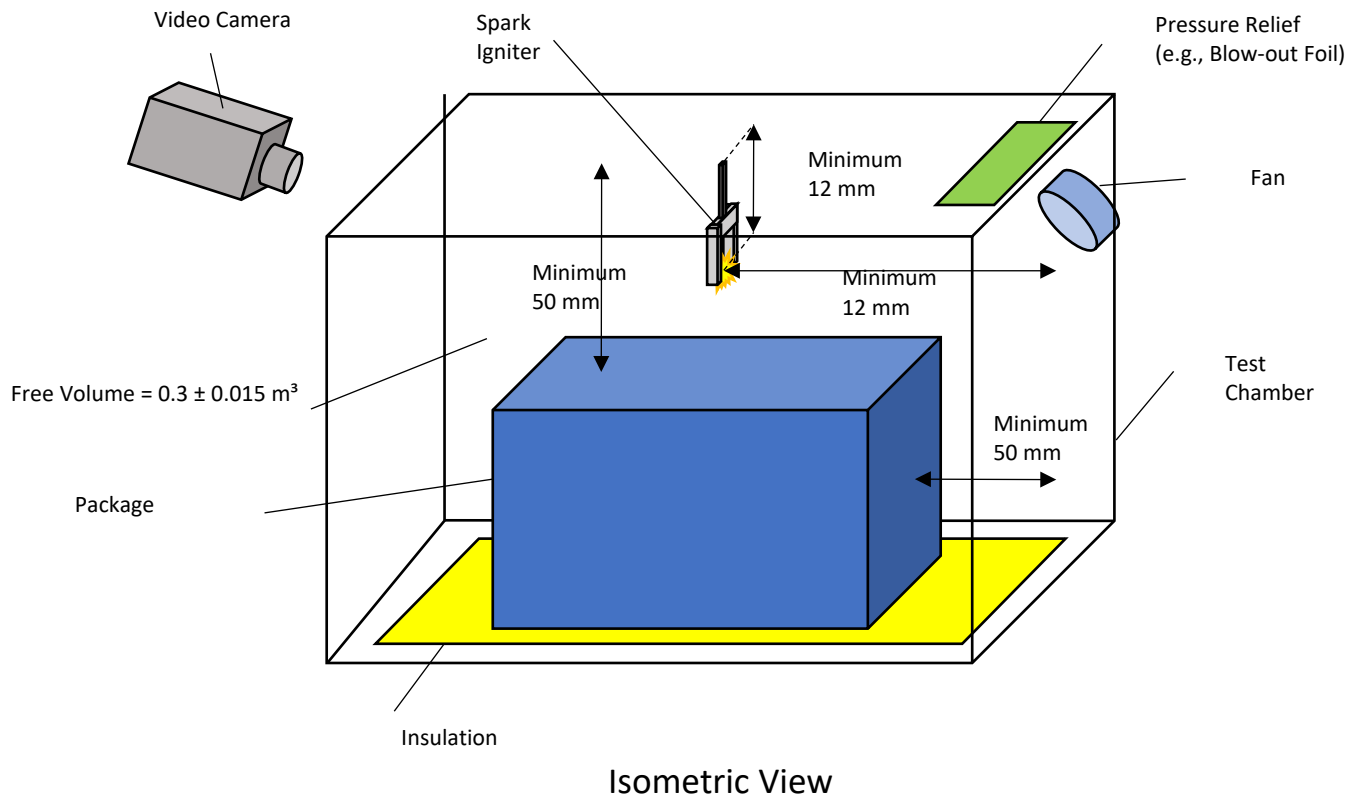


Figure 2 - Example placement of the test article in the test chamber showing the overhead central location of the spark igniter and the side-mounted circulation fan