JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL 3030:2018 (R2024)

STANDARD FOR SAFETY

Unmanned Aircraft Systems

ANSI/UL 3030-2018 (R2024)

SCC FOREWORD

National Standard of Canada

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UL Standard for Safety for Unmanned Aircraft Systems, ANSI/CAN/UL 3030

First Edition, Dated September 18, 2018

Summary of Topics

This revision of ANSI/CAN/UL 3030 dated August 30, 2024 is being issued to update the title page to reflect the latest ANSI and SCC approval dates as a Reaffirmed American National Standard (ANS) and National Standard of Canada (NSC). No changes in requirements are involved.

Text that has been changed in any manner or impacted by ULSE's electronic publishing system is marked with a vertical line in the margin.

The requirements are substantially in accordance with Proposal(s) on this subject dated May 31, 2024.

No Text on This Page

ANSI/UL 3030-2018 (R2024)

SEPTEMBER 18, 2018
(Title Page Reprinted: August 30, 2024)

ANSI/CAN/UL 3030:2018 (R2024)

Standard for Unmanned Aircraft Systems

First Edition

September 18, 2018

This ANSI/CAN/UL Safety Standard consists of the First Edition including revisions through August 30, 2024.

The most recent designation of ANSI/UL 3030 as a Reaffirmed American National Standard (ANS) occurred on August 30, 2024. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This standard has been designated as a National Standard of Canada (NSC) on August 30, 2024.

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Preface

This is the First Edition of the ANSI/CAN/UL 3030 Standard for Safety for Unmanned Aircraft Systems.

ULSE is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 3030 Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

Annex A is identified as Normative, as such, forms mandatory parts of this Standard.

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

Comments or proposals for revisions on any part of the Standard may be submitted to ULSE at any time. Proposals should be submitted via a Proposal Request in ULSE's Collaborative Standards Development System (CSDS) at https://csds.ul.com.

This Edition of the Standard has been formally approved by the Technical Committee (TC) on Unmanned Aircraft Systems, TC 3030.

This list represents the TC 3030 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

TC 3030 Membership

Name	Representing	Interest Category	Region
Albuquerque, Paul V	Federal Aviation Administration	Government	USA
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Feng, Drew	Xiamen Ampace Technology Limited	Supply Chain	China
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TC 3030 Membership Continued on Next Page

TC 3030 Membership Continued

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International Classification for Standards (ICS): 49.020; 29.220

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This Standard is intended to be used for conformity assessment.

The intended primary application of this standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

CETTE NORME NATIONALE DU CANADA EST DISPONIBLE EN VERSIONS FRANÇAISE ET ANGLAISE.

INTRODUCTION

1 Scope

1.1 These requirements cover the electrical system of unmanned aircraft systems (UASs), as defined in this Standard, used in flight for commercial applications or flight incidental to business applications. UASs covered by these requirements are intended to be operated by certified UAS pilots as identified in the Federal Regulations, where the unmanned aircraft is less than 25 kg (55 lbs). The UAS is intended to be provided with an internal lithium ion battery that is charged from an external source. UASs are intended to have an operating voltage of not greater than 100 V dc, and are intended for outdoor operation. These requirements also cover the electrical shock, fire and explosion hazards associated with the inherent features of these UASs, as well as the battery and charger system combinations provided for recharging the UAS.

1.2 With reference to 1.1, flight for commercial applications is considered any operation where the UAS is intended for a specific use; which may include, but is not limited to, agricultural applications, scientific or research applications, government or local police applications, search and rescue applications, video applications for the film industry or news broadcasts, and the like. Flight incidental to business is a subset of commercial applications that may consist of roof inspections by insurance agents or construction workers, real estate photography, and the like.

1.3 This Standard does not cover:

a) Model aircraft, or hobby use, UASs which are marketed to and intended to be operated by the general public;

b) The aspects of control associated with the human pilot (pilot error), UAS handling, contact or impact of the UAS with external objects, people or structures, or adverse weather conditions such as high winds that may affect operation, or the general airworthiness of the aircraft;

c) The ability of the UAS to correctly or adequately perform its intended operation;

d) The ability of the UAS to land safely if the battery is discharged in flight;

e) Any physiological effects associated with the use of UASs;

f) Devices for use in hazardous (classified) locations, which are subject to additional requirements to mitigate risks of fire and explosion;

g) UASs used for any military or similar tactical operation; or

h) The efficacy of UAS communications or the effects of the loss of UAS communication during flight.

1.4 The requirements of this Standard do not consider Federal Regulations associated with the operation of commercial UASs. The operation of commercial UASs is intended to be in accordance with all Federal Regulations when the UAS is used.

2 Components

2.1 A component of a product covered by this Standard shall comply with the requirements for that component.

2.2 A component is not required to comply with a specific requirement that:

a) Involves a feature or characteristic not required in the application of the component in the product covered by this Standard, or

b) Is superseded by a requirement in this Standard.

2.3 A component shall be used in accordance with its rating established for the intended conditions of use.

2.4 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

3 Units of Measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

4 Undated References

4.1 Any undated reference to a code or standard appearing in the requirements of this Standard shall be interpreted as referring to the latest edition of that code or standard.

5 Normative References

5.1 Products covered by this standard shall comply with the reference standards noted in this section as appropriate for the country where the product is to be used. When the product is intended for use in more than one country, the product shall comply with the standards for all countries where it is intended to be used.

5.2 The following standards are referenced in this standard, and portions of these referenced standards as identified in this standard may be essential for compliance.

ASTM Standards

ASTM D412
Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension

ANSI/ASTM E230/E230M
Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples

ASTM F2908
Specification for Aircraft Flight Manual (AFM) for a Small Unmanned Aircraft System (sUAS)

ASTM F2909
Practice for Maintenance and Continued Airworthiness of Small Unmanned Aircraft Systems (sUAS)

ASTM F2910
Specification for Design and Construction of Small Unmanned Aircraft Systems (sUAS)

ASTM F3005
Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS)

CSA Standards

CSA C22.2 No. 0.2
Insulation Coordination

CSA C22.2 No. 0.8
Safety Functions Incorporating Electronic Technology

CAN/CSA C22.2 No. 0.17
Evaluation of Properties of Polymeric Materials

CSA C22.2 No. 94.2
Electrical Equipment, Environmental Consideration

CSA C22.2 No. 100
Motors and Generators

CSA C22.2 No. 107.1
Power Supplies

CSA C22.2 No. 210
Appliance Wiring Material Products

CSA C22.2 No. 223
Power Supplies With Extra Low Voltage Class 2 Outputs – General Instructions No. 1

CSA 248 series
Low Voltage Fuses

CSA C22.2 No. 282
Plugs, Receptacles, and Couplers for Electric Vehicles

CSA 4248 series
Fuseholders

CSA C22.2 E60730-1
Automatic Electrical Controls – Part 1: General Requirements

CSA C22.2 No. 60950-1
Information Technology Equipment – Safety – Part 1: General Requirements

CSA C22.2 No. 60950-22
Information Technology Equipment – Safety – Part 22: Equipment to be installed outdoors

CSA C22.2 No. 62133
Standard for 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,

CSA C22.2 No. 62368-1
Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements

IEC Standards

IEC 60068-2-64

Environmental Testing – Part 2-64: Tests – Test Fh: Vibration, Broadband Random and Guidance

IEC 60529
Degrees of Protection Provided by Enclosures (IP Code)

IEC 60812
Analysis Techniques for System Reliability – Procedure for Failure Mode and Effects Analysis (FMEA)

IEC 60695-2-12
Fire hazard testing – Part 2-12: Glowing/hot-wire based test methods – Glow-wire flammability index (GWFI) test method for materials

IEC 61025
Fault Tree Analysis (FTA)

IEC 61508-1 and all parts
Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems – Part 1: General Requirements

ISO Standards

ISO 12405-1
Electrically Propelled Road Vehicles – Test Specification for Lithium-Ion Traction Battery Packs and Systems – Part 1: High-Power Applications

SAE Standards

SAE J1739
Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA)

UL Standards

UL 50E
Enclosures for Electrical Equipment, Environmental Considerations

UL 94
Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

UL 157
Gaskets and Seals

UL 248 series
Low Voltage Fuses

UL 746B
Polymeric Materials – Long Term Property Evaluations

UL 746C
Polymeric Materials – Use in Electrical Equipment Evaluations

UL 758
Appliance Wiring Materials

UL 796
Printed Wiring Boards

UL 840
Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment

UL 991
Tests for Safety-Related Controls Employing Solid-State Devices

UL 1004-1
Rotating Electrical Machines – General Requirements

UL 1012
Power Units other than Class 2

UL 1310
Class 2 Power Units

UL 1642
Lithium Batteries

UL 1998
Software in Programmable Components

UL 2251
Plugs, Receptacles, and Couplers for Electric Vehicles

UL 2271
Batteries for Use in Light Electric Vehicle (LEV) Applications

UL 2580
Batteries for Use in Electric Vehicles

UL 4248 series
Fuseholders

UL 60730-1
Automatic Electrical Controls – Part 1: General Requirements

UL 60950-1
Information Technology Equipment – Safety – Part 1: General Requirements

UL 60950-22
Information Technology Equipment – Safety – Part 22: Equipment to be installed outdoors

UL 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

UL 62368-1
Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements

ULC Standards

CAN/ULC-S2271
Batteries for Use In Light Electric Vehicle (LEV) Applications

CAN/ULC-S2580
Batteries for Use in Electric Vehicles

US Department of Defense (DOD) Standards

MIL-STD-1629A
Procedures for Performing a Failure Mode, Effects, and Criticality Analysis

6 Glossary

6.1 For the purpose of this Standard the following definitions apply.

6.2 BATTERY – A generic term for one or more cells electrically connected in series and/or parallel with or without monitoring and protection circuitry for charging and discharging.

6.3 BATTERY PACK – Batteries that are ready for use in a UAS, contained in a protective enclosure, with protective devices, with a battery management system, and monitoring circuitry and that may be removable by the user for charging separately from the UAS.

6.4 BATTERY SYSTEM – Battery system includes the battery, charger and monitoring and protection circuit for charging and discharging of the battery.

6.5 CAPACITY, RATED – The total number of ampere-hours that can be withdrawn from a fully charged battery at a specific discharge rate to a specific end-of-discharge voltage (EODV) at a specified temperature as declared by the manufacturer.

6.6 CASING – The container that directly encloses and confines the electrolyte, and electrodes of a cell.

6.7 CELL – The basic functional electrochemical unit (sometimes referred to as a battery) containing an electrode assembly, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

6.8 CHARGING – The application of electric current to battery terminals, which results in a Faradic reaction that takes place within the battery that leads to stored electro-chemical energy.

6.9 CHARGING, CONSTANT CURRENT (CC) – Charging mode where current is held constant while charging voltage is allowed to vary.

6.10 ELECTRIC SHOCK HAZARD – A potential for exposure of persons to hazardous voltage circuits through direct contact from openings in protective enclosures and/or insufficient insulation between hazardous voltage circuits and accessible parts.

6.11 ELECTRICAL SYSTEM – The system of components, circuits, and related elements of the UAS. The system is comprised of the battery system, motors and motor controllers, protection/safety circuits addressing electrical, fire and explosion hazards, and associated on board electronics.

6.12 ELECTROLYTE LEAKAGE – A condition where liquid electrolyte escapes through an opening in a designed vent as well as through a rupture or crack or other unintended opening in the casing or enclosure of a cell or capacitor and is visible external to the UAS.

6.13 ENCLOSURE – That part of the UAS that renders inaccessible all or any parts of the equipment that may otherwise present a risk of electric shock and or retards propagation of flame initiated by electrical disturbances occurring within.

6.14 END-OF-DISCHARGE VOLTAGE (EODV) – The voltage, under load, of the cell or battery at the end of discharge. The EODV may be specified, as in the case of a voltage terminated discharge, or simply measured in the case of a time-controlled discharge.

6.15 EXPLOSION – A violent release of energy that produces projectiles or an energy wave from the UAS and results in the UAS's contents being forcibly expelled through a rupture in the enclosure or casing.

6.16 FIRE – The sustained combustion of the UAS's contents as evidenced by flame, heat and charring or other damage of materials.

6.17 FULLY CHARGED – A battery which has been charged per the manufacturer's specifications to its full state of charge (SOC).

6.18 FULLY DISCHARGED – A battery, which has been discharged, according to the manufacturer's specifications, to its specified end of discharge voltage (EODV).

6.19 HAZARDOUS VOLTAGE – Voltage exceeding 30 V rms/42.4 V ac peak or 60 V dc.

6.20 INSULATION LEVELS – The following are levels of electrical insulation:

a) BASIC – A single level of insulation that provides protection against electric shock. Basic insulation alone may not provide protection from electric shock in the event of a failure of the insulation.

b) DOUBLE INSULATION – Insulation comprising both basic insulation and supplementary insulation.

c) FUNCTIONAL INSULATION – Insulation that is necessary only for the correct functioning of the equipment. Functional insulation by definition does not protect against electric shock. It may, however, reduce the likelihood of ignition and fire.

d) REINFORCED INSULATION – Single insulation system that provides a degree of protection against electric shock equivalent to double insulation under the conditions specified in this Standard. The term "insulation system" does not imply that the insulation has to be in one homogeneous piece. It may comprise several layers that cannot be tested as basic insulation and supplementary insulation.

e) SUPPLEMENTARY INSULATION – Independent insulation applied in addition to basic insulation in order to reduce the risk of electric shock in the event of a failure of the basic insulation.

6.21 LOW VOLTAGE, LIMITED ENERGY CIRCUIT – A circuit involving a potential of not more than 30 volts rms (42.4 volts peak) or a direct voltage of not more than 60 volts and supplied by a battery, a Class 2 source, or a combination of an isolating transformer and a fixed impedance that, as a unit, limits the available energy to 240 VA maximum.

6.22 NORMAL OPERATING REGION – That region of voltage, current and temperature within which a cell can be safely charged and discharged repetitively throughout its anticipated life. The manufacturer specifies these values, which are then used in the safety evaluation of the device and may vary as the device ages. The normal operating regions will include the

a) CHARGING TEMPERATURE LIMITS – The upper and lower limits of temperature, specified by the manufacturer for charging of the cell. This temperature is measured on the casing.

b) DISCHARGE TEMPERATURE LIMITS – The upper and lower limits of temperature, specified by the manufacturer for discharging the cell. This temperature is measured on the casing.

c) END OF DISCHARGE VOLTAGE – Refer to 6.14.

d) MAXIMUM DISCHARGING CURRENT – The maximum discharging current rate, which is specified by the cell manufacturer.

e) MAXIMUM CHARGING CURRENT – The maximum charging current in the normal operating region, which is specified by the cell manufacturer. This value may vary with temperature.

f) UPPER LIMIT CHARGING VOLTAGE – The highest charging voltage limit in the normal operating region specified by the cell manufacturer. This value may vary with temperature.

6.23 RUPTURE – A mechanical failure of the UAS's battery enclosure/casing from either internal or external causes, that results in spillage and/or exposure of internal contents of the UAS, but does not result in projectiles and violent energy release such as occurs during an explosion.

6.24 SAFETY CRITICAL CIRCUITS/COMPONENTS – Those circuits or discrete components that are relied upon for safety as identified in the safety analysis of Protection Circuits and Safety Analysis, Section 15.

6.25 STATE OF CHARGE (SOC) – The available capacity in a pack, module or cell expressed as a percentage of rated capacity.

CONSTRUCTION

7 General

7.1 If the operation and maintenance of the UAS electrical system by the user involves a risk of injury to persons, a risk of electric shock, or a risk of fire, means shall be provided to reduce the risk. When evaluating a UAS's electrical system, consideration shall be given to reasonably foreseeable misuse of the product.

7.2 All UAS electrical systems shall be capable of normal operation without a risk of fire, shock or injury in accordance with this Standard over the full range of ambient air temperature from 10°C (40°F) to 50°C (122°F) unless a different range is specified by the manufacturer in which case that range is to be used.

8 Nonmetallic Materials

8.1 The polymeric materials employed for enclosures shall comply with the applicable enclosure requirements outlined in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, Path III of the Enclosure Requirements in Table 4.1, and Evaluation of Properties of Polymeric Materials, CAN/CSA C22.2 No. 0.17, except as modified by this Standard. For composite materials, such as carbon fiber, the requirements are as stated in this Standard.

8.2 Polymeric materials employed for enclosures shall have a minimum flame rating of V-1 in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, and Evaluation of Properties of Polymeric Materials, CAN/CSA C22.2 No. 0.17. Composite materials, such as carbon fiber, shall comply with 8.6.

8.3 Alternate construction materials (e.g. carbon fiber) which comply with 550°C Glow Wire Flammability Index (GHWI) in the Standard for Fire hazard testing – Part 2-12: Glowing/hot-wire based test methods – Glow-wire flammability index (GWFI) test method for materials, IEC 60695-2-12, need not be subject to flammability tests.

8.4 Small combustible parts mounted on PCB material inside the fire enclosure need not be subject to flammability test.

8.5 Polymeric materials outside the fire enclosure or flame barrier which meet UL 94 HB need not be subjected to flammability test.

8.6 All composite material enclosures shall be evaluated to the 20 mm end product flame test in accordance with the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, and Evaluation of Properties of Polymeric Materials, CAN/CSA C22.2 No. 0.17. This test may also be used as an alternate means for determining compliance with the flammability of polymeric enclosures in 8.2.

8.7 The following factors in (a) – (e) are taken into consideration when an enclosure employing polymeric or composite materials is being judged. For any nonmetallic enclosure material, all of these factors are to be considered with respect to thermal aging. Dimensional stability of a polymeric enclosure is addressed by compliance to the mold stress relief test. Suitability to factors (a) – (e) below may be determined by the tests in this Standard.

a) Resistance to impact;

b) Crush resistance;

c) Abnormal operations;

d) Severe conditions; and

e) Mold stress relief distortion.

8.8 The polymeric materials employed for enclosures and insulation shall be suitable for anticipated temperatures encountered in the intended application. Enclosures shall have a Relative Thermal Index (RTI) with impact suitable for temperatures encountered in the application but no less than 80°C (176°F), as determined in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, and Evaluation of Properties of Polymeric Materials, CAN/CSA C22.2 No. 0.17. This requirement is not applicable for composite materials such as carbon fiber.

8.9 The enclosure materials intended to be directly exposed to sunlight and rain in the end use application shall comply with the UV Resistance and the Water Exposure and Immersion tests in accordance with the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, and Evaluation of Properties of Polymeric Materials, CAN/CSA C22.2 No. 0.17. This requirement is not applicable for composite materials such as carbon fiber.

8.10 Materials employed as electrical insulation in the assembly shall be resistant to deterioration that would result in an electrical shock, fire or other safety hazard. Compliance is determined by the tests in this Standard. Materials employed for direct support of live parts at hazardous voltage, shall additionally meet the direct support insulation criteria outlined in the Material Property Considerations, Table 6.1, in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, and Evaluation of Properties of Polymeric Materials, CAN/CSA C22.2 No. 0.17, unless employed as part of a component that has been evaluated to a suitable component standard. Insulated wiring is subjected to the requirements outlined in Internal Wiring and Terminals, Section 12.

8.11 Gaskets and seals relied upon to maintain the environmental integrity of the enclosure shall be subjected to the Accelerated Aging Test, the Low Temperature Test, and the Immersion Test in the Standard for Gaskets and Seals, UL 157. For the Immersion Test, the gaskets are immersed in IRM 903 oil to address lubricating oil, and in water to address rain and condensation.

9 Metallic Materials

9.1 Metal enclosures shall be corrosion resistant. A suitable plating or coating process can achieve corrosion resistance. Additional guidance on methods to achieve corrosion protection can be found in the Standard for Enclosures for Electrical Equipment, Environmental Considerations, UL 50E, and Electrical Equipment, Environmental Consideration, CSA C22.2 No. 94.2.

9.2 Metal enclosures may be provided with an insulating liner to prevent shorting of uninsulated live parts to the enclosure, or as an insulating barrier between uninsulated live parts within the enclosure. If an insulating liner is used, the material that is used to form the liner shall comply with the requirements in Nonmetallic Materials, Section 8, and shall be non-moisture absorbent materials that have a temperature rating suitable for temperatures during operation including charging. The insulating liner shall meet all applicable dielectric strength requirements in this Standard.

9.3 Conductive parts in contact at terminals and connections shall not be subject to corrosion due to electrochemical action.

10 Enclosures

10.1 The enclosure shall have the strength and rigidity required to resist the possible physical abuses that it will be exposed to during its intended use in order to reduce the risk of fire or injury to persons as determined by the requirements of this standard.

10.2 The enclosure shall be constructed such that a tool is required to gain access into internal areas of the enclosure. Any user accessible area shall not be accessible by the same tool needed to access a non-user accessible area. A tool is any device that can be used to gain access or any device the user is told to use to access an area.

10.3 Openings in the enclosure shall be designed to prevent inadvertent access to hazardous parts. Compliance is determined by Clause 12 – Tests for Protection Against Access to Hazardous Parts Indicated by the First Characteristic Numeral – of the Standard for Degrees of Protection Provided by Enclosures (IP Code), IEC 60529, for a minimum IP rating of IP3X. Evaluation in accordance with Clause 12 of IEC 60529 consists of the use of the Test Rod (2.5 mm diameter, 100 mm long) shown in Table 6 of IEC 60529, applied with a force of 10 N ±10%.

10.4 Openings in the enclosure shall be designed to prevent ingress of water in accordance with intended use and IP rating in accordance with the Standard for Degrees of Protection Provided by Enclosures (IP Code), IEC 60529, with a minimum rating of IPX4 and resistant to hazards associated with partial immersion. Compliance is determined by the Water Exposure Tests, Section 36. Indoor use only UAS are not required to comply with this requirement.

11 Assembly

11.1 The UAS shall be designed such that structural parts remain secured when subjected to the vibration caused by normal operation. Internal wiring connections shall also remain secured and shall not be freed from their terminals or connections due to the vibration caused by normal operation.

11.2 Compliance with 11.1 is determined by the Vibration Test, Section 33.

12 Internal Wiring and Terminals

12.1 Wiring shall be in accordance with the Standard for Appliance Wiring Materials, UL 758, and Appliance Wiring Material Products, CSA C22.2 No. 210, and shall be insulated and acceptable for the purpose when considered with respect to temperature, voltage, and the conditions of service to which the wiring is likely to be subjected within the equipment.

12.2 Internal wiring shall be routed, supported, clamped or secured in a manner that reduces the likelihood of excessive strain on wire and on terminal connections; loosening of terminal connections; and damage of conductor insulation. For soldered terminations in safety critical circuits, the conductor shall be positioned or fixed so that reliance is not placed upon the soldering alone to maintain the conductor in position.

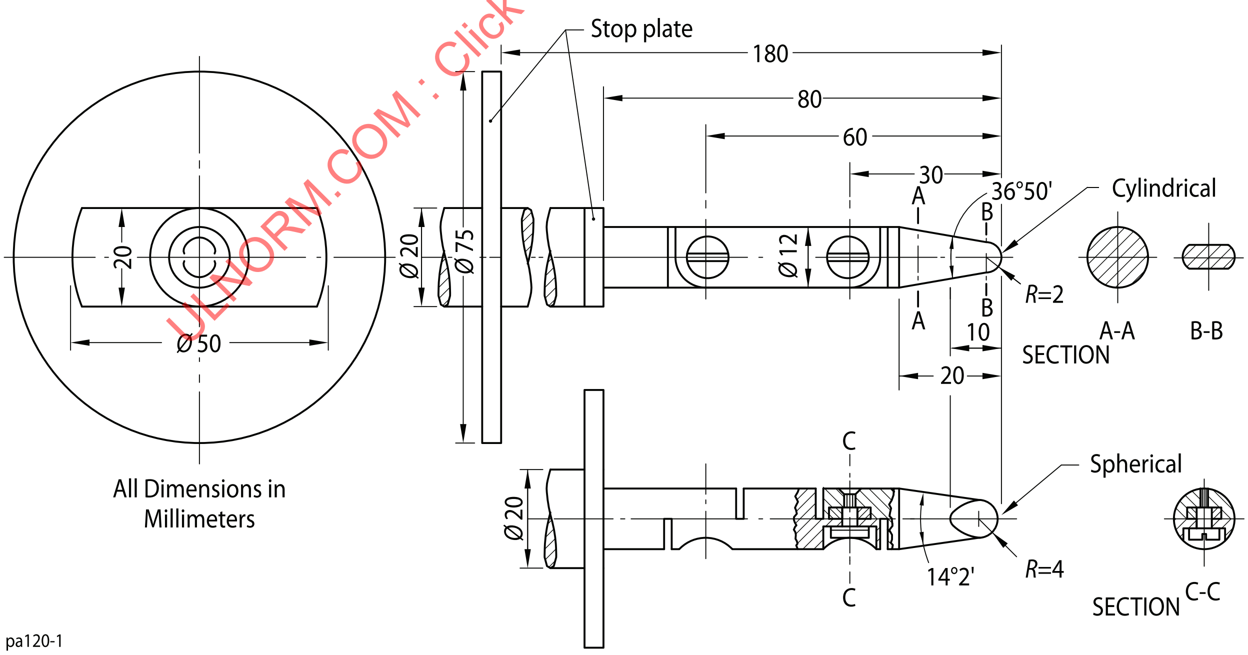
12.3 An external terminal shall be designed to prevent inadvertent shorting if such shorting results in a hazard in accordance with this Standard. An external terminal shall be designed to prevent inadvertent misalignment or disconnection when the UAS is in use.

12.4 An external terminal for charging shall be designed to prevent an inadvertent shorting and misalignment and a reverse polarity connection when connected to the charger.

12.5 For battery packs that are intended for removal from the UAS for external charging or replacement with a charged battery pack, the external terminal for charging shall be designed to prevent inadvertent shorting, a reverse polarity connection, misalignment, or access by the user. User access is determined by use of the articulate test finger shown in Figure 12.1. A battery pack complying with 17.3 is considered to comply with this requirement.

Figure 12.1

Articulate Probe



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12.6 The external terminals of a removable battery pack shall be evaluated to either the no load endurance test or endurance with load test as applicable to the end use application in accordance with the Standard for Plugs, Receptacles, and Couplers for Electric Vehicles, UL 2251 and CSA C22.2 No. 282, without being subjected to the exposure to contaminants.

12.7 A hole by which insulated wires pass through a metal wall shall be provided with a smoothly rounded bushing or shall have smooth surfaces, free of burrs, fins, sharp edges, and the like, upon which the wires may bear, to prevent abrasion of the insulation.

12.8 Wiring for hazardous voltage shall be enclosed and not routed in user access areas.

13 Chargers

13.1 Power supplies intended for charging the UAS shall be determined to be compatible with the UASs battery system and shall be evaluated in accordance with one or more of the following:

a) The Standard for Class 2 Power Units, UL 1310, and Power Supplies With Extra Low Voltage Class 2 Outputs – General Instructions No. 1, CSA C22.2 No. 223;

b) The Standard for Power Units other than Class 2, UL 1012, and Power Supplies, CSA C22.2 No. 107.1;

c) The Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1 and CSA C22.2 No. 60950-1;

d) The Standard for Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements, UL 62368-1 and CSA C22.2 No. 62368-1.

Compliance is determined by a review of data on the battery system and charger and the tests in this Standard. The charger shall be provided with a means for connection to a standard outlet if intended for connection to a mains source of electrical supply in accordance with the standards noted above.

If charging of the battery is to occur outdoors, the charger shall be suitable for outdoor use. For the chargers in (c) and (d), this requires additional compliance with the Standard for Information Technology Equipment – Safety – Part 22: Equipment to be Installed Outdoors, UL 60950-22 and CSA C22.2 No. 60950-22.

13.2 The connector provided with the charger for connecting to the UAS/battery terminal for charging, shall be designed to prevent misalignment and reverse polarity.

14 Insulation Levels and Protective Grounding

14.1 Hazardous voltage circuits shall be insulated from accessible conductive parts and safety extra low voltage (SELV) circuits (i.e. circuits at or below 60 V dc or 48 V rms under normal and single fault conditions) as outlined in 14.2 through the following:

a) Basic insulation and provided with a protective grounding system for protection in the event of a fault of the basic insulation;

b) A system of double or reinforced insulation; or

c) A combination of (a) and (b).

During operation of the UAS, protective grounding will no longer be an option and therefore only (b) applies to UAS in flight.

14.2 Safety extra low voltage (SELV) circuits that are insulated from accessible conductive parts through functional insulation only are considered accessible.

14.3 If relying upon a protective grounding system (i.e. grounding of an accessible metal enclosure), it shall comply with 14.4 – 14.6.

14.4 Parts of a protective grounding system shall be reliably secured in accordance with 12.2 and provided with good metal-to-metal contact of the grounded parts of the UAS during charging. The impedance from the various bonding conductors and connections to the main ground terminal shall have a maximum resistance of 0.1 Ω. Compliance can be determined by measurement using an ohmmeter or other similar device.

14.5 The main ground terminal of the protective grounding system shall be identified by one of the following:

a) A green-colored, not readily removable terminal screw with a hexagonal head;

b) A green-colored, hexagonal, not readily removable terminal nut;

c) A green colored pressure wire connector; or

d) The word "Ground" or the letters "G" or "GR" or the grounding symbol (IEC 60417, No. 5019) or otherwise identified by a distinctive green color.

14.6 Conductors, relied upon for the protective grounding and bonding system, shall be sized to handle intended fault current. If insulated, the insulation shall be green or green and yellow striped in color.

15 Protection Circuits and Safety Analysis

15.1 The battery system shall maintain the cells within their normal operating region, as defined by the manufacturer, for charging and discharging through the life of the UAS. If normal limits are exceeded, the protective circuit shall limit or shut down the charging or discharging to prevent excursions beyond normal operating limits. Compliance is determined through a review of the battery system data including the safety analysis of 15.3 and through the tests in this Standard.

15.2 Protection circuits used to monitor operational parameters (e.g. monitoring motor temperature, motor RPM, battery conditions, and the like) shall also be evaluated based on the requirements in this section. Compliance is determined through a review of the design and overall system, including the safety analysis of 15.3 and through the tests in this Standard.

15.3 An analysis of potential hazards (including an FMEA) shall be conducted on the UAS's electrical system to determine that events that could lead to a hazardous condition associated with the electrical, fire and explosion performance of the electrical system have been identified and addressed through design or other means. Documents that can be used as guidance for the safety analysis include:

a) The Standard for Analysis Techniques for System Reliability – Procedure for Failure Mode and Effects Analysis (FMEA), IEC 60812;

b) The Standard for Fault Tree Analysis (FTA), IEC 61025;

c) The Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA), SAE J1739; and

d) The Procedures for Performing a Failure Mode, Effects, and Criticality Analysis, MIL-STD-1629A.

Other standards that are considered to provide equivalent analysis methods and results are also acceptable.

15.4 The analysis in 15.3 is utilized to identify anticipated faults in the system which could lead to a hazardous condition and the types and levels of protection provided to mitigate the anticipated faults. The analysis shall consider single fault conditions in the protection circuit/scheme as part of the anticipated faults.

15.5 When conducting the analysis of 15.3, active devices shall not be relied upon for critical safety unless:

a) They are provided with a redundant passive protection device; or

b) They are provided with redundant active protection that remains functional and energized upon loss of power/failure of the first level active protection; or

c) They are determined to fail safe upon loss of power to the active circuit.

15.6 Devices relied upon for critical safety as noted in 15.3 shall be tested for functionality in accordance with appropriate functional safety requirements unless already evaluated through the other tests in this Standard. Functional safety criteria for UAS electrical systems can be found in one of the following standards as appropriate to the design of the electronic and software protection scheme:

a) The Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, and the Standard for Software in Programmable Components, UL 1998, and Safety Functions Incorporating Electronic Technology, CSA C22.2 No. 0.8;

b) The Standard for Automatic Electrical Controls – Part 1: General Requirements, UL 60730-1, and Automatic Electrical Controls – Part 1: General Requirements, CSA C22.2 E60730-1; and

c) The Standard for Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems – Part 1: General Requirements, IEC 61508-1, and all parts.

15.7 Any UAS electrical system containing hazardous voltage shall have a manual disconnect to prevent inadvertent access to hazardous voltage parts during servicing. The manual disconnect shall:

a) Disconnect both poles of the hazardous voltage circuit;

b) Be accessible and able to be operated without the use of a tool in the event of a collision or during servicing;

c) Require manual action to break the electrical connection;

d) Ensure disconnection is physically verifiable and can include actual removal of the battery system from the UAS or unplugging the battery system connector/plug; and

e) When engaged (i.e. under disconnection), it does not create exposed conductors capable of becoming energized and is insulated to prevent a shock hazard during actuation.

15.8 If a hazardous voltage automatic disconnect device is provided to isolate accessible conductive parts from the hazardous voltage circuit of the battery system, it shall:

a) Not be able to be reset automatically although it may be able to be reset deliberately upon clearing of the fault;

b) Disconnect both poles of the hazardous voltage circuit;

c) Be capable of handling full load disconnects of the hazardous voltage circuit that it is isolating; and

d) Not result in a hazardous condition upon automatic actuation.

16 Printed Wiring Boards

16.1 A printed wiring board shall comply with the requirements in the Standard for Printed Wiring Boards, UL 796, and have a minimum flammability classification of V-1.

16.2 A resistor, capacitor, inductor, or other part that is mounted on a printed wiring board to form a printed wiring assembly shall be secured so that it cannot be displaced to cause a risk of fire or electric shock by a force likely to be exerted on it during assembly, normal operation, or servicing of the UAS.

16.3 Consideration is to be given to a barrier or partition that is part of the UAS assembly and that provides mechanical protection, a flame barrier, or electrical insulation for a component connected to a printed wiring board.

17 Battery Cells and Battery Packs

17.1 General

17.1.1 Batteries provided in UASs may be provided as cells combined into a custom configuration within the UAS or as complete battery packs. If provided as cells, the cells shall comply with 17.2. If provided as a battery pack, the pack shall comply with 17.3. If battery packs in accordance with 17.3 are used, then the cells of the battery pack are not required to be evaluated in accordance with 17.2.

17.1.2 If the battery pack, custom or not, is user replaceable or removed for charging, the battery shall be keyed or designed so that it only enters the battery entry on the UAS in one direction. If this is not the case, then the Internal Battery Reverse Polarity Test, Section 32.5 shall be performed.

17.2 Battery cells

17.2.1 Cells shall be designed to safely withstand anticipated abuse conditions for UAS's electrical systems. Compliance is determined by the requirements in 17.2.2 and by the tests in this Standard. Cells that are part of a battery pack in accordance with 17.3 are not required to be evaluated.

17.2.2 Lithium ion and other lithium based cells shall comply with the requirements for secondary lithium cells in the Standard for Batteries for Use in Electric Vehicles, UL 2580 and CAN/ULC-S2580, or the Standard for Lithium Batteries, UL 1642.

17.2.3 The temperature limits need to consider the cell manufacturer's specified temperature limits on the cell casing surface during charging and discharging. When evaluating the cell and battery control combination, consideration must be given to tolerances in the control circuitry for charging. If the control circuitry settings with tolerances exceed the cell charge specifications for voltage, testing of the cell needs to be repeated with the cell charged to these higher voltage values.

17.3 Battery packs

17.3.1 Battery packs shall be provided with an appropriate Battery Management System (BMS), and shall be designed to safely withstand anticipated abuse conditions for UAS's electrical systems, including anticipated abuse associated with removable battery packs. Compliance is determined by the requirements in 17.3.2.

17.3.2 A battery pack used in a UAS shall be in accordance with:

a) The Standard for Batteries for Use in Electric Vehicles, UL 2580 and CAN/ULC-S2580,

b) The Standard for Batteries for Use in Light Electric Vehicle (LEV) Applications, UL 2271 and CAN/ULC-S2271, or

c) The Standard for 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, UL 62133 and CSA C22.2 No. 62133.

17.3.3 A battery pack in accordance with 17.3.2(c) is required to comply with the requirements in Overcharge Test, Section 32.6; Short Circuit Test, Section 32.7; Imbalanced Charging Test, Section 32.8; Shock Test, Section 32.9; Vibration Test (battery method), Section 33.1; and Thermal Cycling Test, Section 32.10.

18 Motors

18.1 A motor used in a UAS shall not be hazardous under overload conditions. Compliance is determined by the tests in this Standard unless previously evaluated as part of a motor and motor protector combination evaluation.

18.2 Motors shall be capable of carrying the maximum normal anticipated load without exceeding temperatures on insulation and windings as determined during the temperature test.

18.3 Motors located in hazardous voltage circuits shall comply with the requirements of the Standard for Rotating Electrical Machines – General Requirements, UL 1004-1, and Motors and Generators, CSA C22.2 No. 100. Motors located in low voltage circuits shall comply with either those standards or the requirements of this Standard.

19 Spacings and Separation of Circuits

19.1 Within the UAS, electrical circuits at opposite polarity shall be provided with reliable physical spacing to prevent inadvertent short circuits (i.e. electrical spacings on printed wiring boards, physical securing of uninsulated leads and parts, etc.). Insulation suitable for the anticipated temperatures and voltages shall be used where spacings cannot be controlled by reliable physical separation.

19.2 The spacing requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, and Insulation Coordination, CSA C22.2 No. 0.2, are to be used. For determination of clearances, Overvoltage Category II applies to UAS that are charged by connecting to the socket outlet in the wall, or Overvoltage Category I for UAS where the battery is removed from the UAS for charging and is charged by an SELV source. The anticipated pollution degree will be Pollution Degree 3 based on outdoor use or Pollution Degree 2 for indoor use only UAS. The Pollution Degree applied can be further reduced in accordance with construction considerations in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840.

19.3 For voltage above 60 V dc or above 30 V rms, there are no minimum spacings applicable to parts where insulating compound completely fills the casing of a component or subassembly if the distance through the insulation is a minimum of 0.4-mm (0.02-inch) for supplementary or reinforced insulation. Additionally, the insulation shall comply with the Dielectric Voltage Withstand Test, Section 29, and the Isolation Resistance Test, Section 30. For voltage less than 60 V dc or 30 V rms, there is no minimum insulation thickness requirement where insulating compound completely fills the casing of a component or subassembly. Some examples include potting, encapsulation, and vacuum impregnation.

19.4 Conductors of circuits operating at different voltages shall be reliably separated from each other through the use of mechanical securements such as barriers or wire ties to maintain spacing requirements unless they are each provided with insulation acceptable for the highest voltage involved. An insulated conductor shall be reliably retained so that it cannot contact an uninsulated live part of a circuit operating at a different voltage.

20 Fuses

20.1 Fuses provided for protection of circuits or outputs shall comply with the applicable parts of the Standard for Low Voltage Fuses, UL 248 series and CSA 248 series. Fuseholders used with these fuses shall comply with the corresponding parts of the Standard for Fuseholders, UL 4248 series and CSA 4248 series. Fuses shall be acceptable for the current and voltage of the circuit they are protecting.

20.2 For user replaceable fuses, a fuse replacement marking giving the fuse ratings shall be located adjacent to each fuse or fuse holder, or on the fuse holder, or in another location provided that it is obvious to which fuse the marking applies. Where user replaceable fuses with special fusing characteristics such as time delay or breaking capacity are necessary, the type of fuse shall also be indicated. Information on proper fuse replacement of user replaceable fuses shall also be included in the instructions.

21 Accessories

21.1 Any integral electrical accessory provided with the UAS, such as cameras, lights, and the like, shall be evaluated to the applicable safety standard for that device. As an alternative for electrical accessories powered from a low voltage, limited energy circuit, the electrical accessory shall be evaluated to the requirements of this Standard.

21.2 The mounting means of the accessory shall be evaluated for securement such that the accessory will not fall from the unmanned aircraft during flight.

PROTECTION AGAINST INJURY

22 Sharp Edges

22.1 An enclosure, an opening, a frame, a guard, a knob, a handle, or the like, shall not be sufficiently sharp to cause a risk of injury to persons in normal maintenance or use. This requirement does not apply to propellers that are intended to have a degree of sharpness to perform their intended function.

23 Strength of Enclosures

23.1 The enclosure shall be tested in accordance with the Strength of Enclosures Tests, Section 34.

PERFORMANCE

24 General

24.1 Unless indicated otherwise, UAS batteries shall be fully charged in accordance with the manufacturer's specifications for conducting the tests in this Standard. After charging and prior to testing, the batteries shall be allowed to rest for a minimum period of 6 h and a maximum period of 8 h at room ambient.

24.2 Unless otherwise indicated, fresh samples representative of production are to be used for the tests described in this Standard. The test program and number of samples to be used in each test is shown in Table 24.1. In accordance with the notes in the table, the number of samples may be reduced. The number of battery packs required to operate the UAS are required with each sample. All test durations are typically correlated to the operational duration of a fully charged battery pack unless otherwise indicated.

Table 24.1
Tests and sample requirements

Test	Clause	Sample[a] (X = UAS, Y = Battery Pack)[e]									
		1	2	3	4	5	6	7	8	8	10
Input Verification	27	X									
Temperature Test (Charging and Flying)	28	X									
Dielectric Voltage Withstand Test	29	X									
Isolation Resistance Test	30	X									
Capacitor Discharge Test	31	X									
Component Faults[b]	32.2		X								
Relay and Solenoid Burnout[c]	32.3		X								
Disconnected Fans / Blocked Vents	32.4	X									
Internal Battery Reverse Polarity[b]	32.5			Y							
Overcharge	32.6				Y						
Short Circuit	32.7					Y					
Imbalanced Charging	32.8							Y			
Shock Test	32.9								Y		
Thermal Cycling	32.10									Y	
Vibration Test	33										Y
Impact[d]	34.1	X	X								
Drop[d]	34.2				X	X					
Mold Stress	35			X							
IPX4 Code Rating	36.1						X				
Temporary Immersion	36.2							X			
Accelerated Aging of Gaskets[c]	37	X									
Permanence of Marking	38		X								
Motor Overload[c]	39	X									

[a] The number of samples shown is considered worst case. Samples that remain operational after the tests indicated for that sample may be used for other tests.

[b] The test involves multiple conditions, all of which are potentially destructive, and will render the sample inoperable. Replacement parts can be used as needed rather than submitting a complete new sample.

[c] The test involves a specific component that can be tested either in or out (bench testing) of the main sample. Separate samples of the component can be used or the component can be taken from the overall sample for testing.

[d] The test requires more than one sample, and each sample is tested at a different condition. The indication in the table covers a sample for each condition, and is not meant to indicate a repeat of the test.

[e] Tests that indicate a sample of the UAS is needed also requires all battery packs required to operate the UAS as intended. For tests that indicate battery pack samples are needed, the original UAS may be used for the test provided it is not damaged by previous testing. In such a case, additional samples of the UAS may be needed.

24.3 All tests, unless noted otherwise, are conducted in a room ambient 25 ±5°C (77 ±9°F).

24.4 Temperature shall be measured using thermocouples. Thermocouples are to consist of wires not larger than 0.21 mm^2 (24 AWG) and not smaller than 0.05 mm^2 (30 AWG). Whenever reference temperature measurements by thermocouples are necessary, thermocouples consisting of 0.05 mm^2 (30 AWG) iron and constantan wire and a potentiometer-type instrument are to be used. The thermocouple wire is to conform with the requirements specified in the Tolerances on Initial Values of EMF versus Temperature tables in the Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples, ANSI/ASTM E230/E230M. For those tests that require the sample to reach thermal equilibrium (also referred to as steady state conditions), thermal equilibrium is considered to be achieved after three successive readings taken at intervals of 10 % of the previously elapsed test duration, but not less than 5 min intervals, indicate no change in temperature greater than ±2°C (±3.6°F).

24.5 Where there is a specific reference to a single fault condition in the individual test methods, the single fault is to consist of a single failure (i.e. open, short or other failure means) of any component in the UAS electrical system that could occur and affect the results of the test. This fault is implemented in conjunction with the test being conducted (i.e. overcharge, short circuit, etc.) or may be conducted as part of a verification of a protective circuit. A protective device determined to be reliable may remain in the circuit without being faulted. A protective device determined to be reliable is one that has been shown to comply with an appropriate component safety standard and is used within its ratings.

24.6 The tests contained in this Standard may result in explosions, fire and emissions of flammable and/or toxic fumes as well as electric shock. It is important that personnel use extreme caution and follow local and regional worker safety regulations when conducting any of these tests and that they be protected from flying fragments, explosive force, and sudden release of heat and noise that could result from testing. The test area is to be well ventilated to protect personnel from possible harmful fumes or gases. As an additional precaution, the temperatures on surface of at least one cell/module within the battery pack are to be monitored during the test for safety and information purposes. All personnel involved in the testing are to be instructed to never approach the sample or the battery pack until temperatures are falling and have returned to within ambient temperatures.

24.7 Unless noted otherwise in the individual test methods, the tests shall be followed by a 1 h observation time prior to concluding the test and temperatures are to be monitored in accordance with 24.6.

24.8 In the tests in this Standard, wherever there is a reference to the use of cheesecloth, the cheesecloth is to be untreated cotton cloth running 26 – 28 m^2/kg (14 – 15 square yards per pound), and having, what is known in the trade as a "count of 13 by 11", that is, for any square centimeter, 13 threads in one direction and 11 threads in the other direction (for any square inch, a count of 32 threads in one direction and 28 in the other direction).

25 Tolerances

25.1 Unless noted otherwise in the test methods, the overall accuracy of measured values of test specifications or results when conducting testing in accordance with this Standard shall be within the following values of the measurement range.

a) ±1% for voltage;

b) ±1% for current;

c) ±2°C (±3.6°F) for temperature at or below 200°C (392°F) and ±3% for temperatures above 200°C (392°F);

d) ±0.1% for time; and

e) ±1% for dimension.

26 Post-Test Cycle

26.1 UAS electrical systems that are operational after the following tests shall be subjected to a minimum of one cycle of charging and discharging in accordance with the manufacturer's specifications to determine that there is no non-compliant results as outlined in Table 26.1 for that test:

a) Electrical Tests – Overcharge, short circuit, imbalanced charging;

b) Mechanical Tests – Vibration, shock; and

c) Environmental Tests – IPX4 Verification, partial immersion, and thermal cycling.

Table 26.1
Noncompliant test results

Non-compliant results	Designation	Tests [a]
Explosion	E	All tests
Fire	F	All tests
Rupture (enclosure)	R	All tests except crush
Electrolyte Leakage (external to enclosure)	L	All tests except crush
Electric shock hazard (resistance below isolation resistance limits or dielectric breakdown)	S	All tests (if hazardous voltage)

[a] For tests that evaluate one specific part of the UAS such as the mold stress, dielectric voltage withstand, isolation resistance, strain relief, and label permanence tests; only those compliance criteria noted in the tests method need be applied. See individual tests for additional compliance criteria details.

27 Input Verification

27.1 The current input to the UAS while charging, and under maximum normal load allowed while charging, shall not exceed 110 % of the current rating specified by the manufacturer of the UAS. If charged from an external source, the measured input current shall not exceed the marked rated output current of the external source.

27.2 Maximum normal load shall consist of the maximum current draw while the UAS is charging. For example, this may include charging the battery while additional loads are operated for diagnostics, cooling, lighting, and the like. Any load that can be operated during charging shall be operated in order to obtain the maximum normal load.

28 Temperature Test (Charging and Flying)

28.1 This test is conducted to determine whether or not temperature sensitive safety critical components and temperature sensitive materials in the UAS are being maintained within their temperature ratings based upon the maximum operating temperature limits of the component or material. During this test, it shall also be determined as to whether or not the component cells are being maintained within their specified operating limits during maximum charge and discharge conditions of the UAS. Temperatures on accessible surfaces, which may be contacted by the user, are also monitored.

28.2 For this test, the battery shall be charged in the UAS where that is inherently required or is allowed as an option. If the battery must inherently be removed for charging, then that configuration shall be used for the test.

28.3 During this test, temperatures are being monitored. In cases where reference is made to the stability of the measured temperature, stability is defined as no change in the measured temperature exceeding 1°C (2°F) over a 5 min period.

28.4 The test consists of charge and discharge cycles until temperatures are stable. The charge cycle consists of charging the battery from fully discharged to fully charged in accordance with the manufacturer’s instructions. The discharge cycle consists of operating the UAS until the UAS is no longer capable of performing as intended due to discharge of the battery. For UAS with non-removable batteries, the charging cycle portion of the test is performed with the battery in the UAS; and for UAS with removable batteries, the charge cycle is performed with the battery removed from the UAS. The complete test involves repeating the charge and discharge cycles until the temperatures are stable in accordance with 28.3.

28.5 With reference to 28.3, for UAS with non-removable batteries, one cycle consists of charging the battery and then operating the UAS. For UAS with removable batteries, the test requires two sets of battery packs. One cycle consists charging the first set of battery packs; then installing the first set of battery packs in the UAS; and then operating the UAS until the battery packs are discharged while charging the second set of battery packs. During repeated cycles the sets of battery packs are interchanged as needed to maintain operation as close to continuous as possible. It is understood that the charge time and the discharge time are typically not the same. If there is a wide discrepancy in the duration for charging and discharging, more than two sets of battery packs may be needed. The cycles are repeated until the temperatures are stable.

28.6 During the temperature test, the voltage and current during discharge and charging of the component cells is monitored to determine that they are not outside of the specified cell manufacturer's operating region.

28.7 The manufacturer's specified limits (voltage, current and temperatures measured) shall not be exceeded during the charging and discharging cycles. Temperatures measured on components shall not exceed their specifications. See Table 28.1 and Table 28.2 for surface and component temperature limits.

Table 28.1
Temperatures on components

Part	Maximum temperatures on components (T_{max}) °C (°F)
Capacitors	
(a) Electrolytic	65 (149)
(b) Other Types[a]	90 (194)
Fuses[b]	90 (194)
Relay, solenoid, and coils (except transformers) with:	
(a) Class 105 (A) insulation	
Thermocouple Method	90 (194)
Resistance Method	110 (230)
(b) Class 130 (B) insulation	
Thermocouple Method	110 (230)
Resistance Method	120 (248)
Sealing Compound[c]	65 (149)

Table 28.1 Continued on Next Page

Table 28.1 Continued

Part	Maximum temperatures on components (T_{max}) °C (°F)
Synthetic rubber or PVC insulation of internal and external wiring	
– without temperature marking	75 (167)
– with temperature marking	Temperature marking
Components, insulation and thermoplastic materials	d
Cell casings	e
Motor Windings[f]:	
• Insulation Class A (open motor)	65
• Insulation Class A (totally enclosed motor)	70
• Insulation Class B (open motor)	85
• Insulation Class B (totally enclosed motor)	90
• Insulation Class F (open motor)	110
• Insulation Class F (totally enclosed motor)	115

[a] A capacitor is to be judged on the basis of its marked temperature limit when it operates at a temperature exceeding 105°C (221°F).

[b] A fuse that has been investigated, and found to comply with requirements for use at a higher temperature is able to be used at that temperature.

[c] The temperature rise limit for sealing compounds indicates the maximum rise that may be observed on a sealing compound. However, the maximum temperature of the sealing compound shall not exceed the melting point of the sealing compound regardless of overall temperature rise.

[d] The temperatures measured on components and materials shall not exceed the maximum temperature rating for that component or material.

[e] The internal cell case temperature shall not exceed the manufacturer's recommended maximum temperature.

[f] The temperature limits are based upon thermocouple measurements.

Table 28.2
Temperatures on user accessible surfaces

Accessible surfaces	Maximum surface temperatures		
	Metal °C (°F)	Glass, porcelain and vitreous materials °C (°F)	Plastic and rubber[a] °C (°F)
Handles, knobs, grips, etc., continuously held in normal use	55 (131)	65 (149)	75 (167)
Handles, knobs, grips, etc., held or touched for short periods only	60 (140)	70 (158)	85 (185)
External surfaces of equipment which may be touched[b]	70 (158)	80 (176)	95 (203)
Parts inside equipment which may be touched[c]	70 (158)	80 (176)	95 (203)

[a] For each material, account shall be taken of the data from that material to determine the appropriate maximum temperature.

[b] For areas on the external surface of equipment and having no dimension exceeding 50 mm (2.0 inches), and which are not likely to be touched in normal use, temperatures up to 100°C (212°F) are permitted.

[c] Temperatures exceeding the limits are permitted provided that the following conditions are met:

1) Unintentional contact with such a part is unlikely;

2) The part has a marking indicating that this part is hot. It is permitted to use the symbol (IEC 60417, No. 5041) to provide this information.

28.8 At the conclusion of the observation period, UAS samples that contain hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 29 or an Isolation Resistance Test, Section 30, (without humidity conditioning).

28.9 As a result of the test, there shall be no indication of any noncompliant results as outlined in Table 26.1. Additionally, the observed temperatures shall not exceed the limits in the tables in this section.

29 Dielectric Voltage Withstand Test

29.1 This test is an evaluation of the electrical spacings and insulation at hazardous voltage circuits within the UAS.

29.2 Circuits at 60 V dc or higher shall be subjected to a dielectric withstand voltage consisting of a dc potential of twice the rated voltage.

29.3 For those circuits connected to an ac mains supply, the test voltage shall be an essentially sinusoidal ac potential of 60 Hz at 1,000 V plus twice the rated voltage. If using a dc potential, the test voltage shall be 1.414 times the ac test potential value.

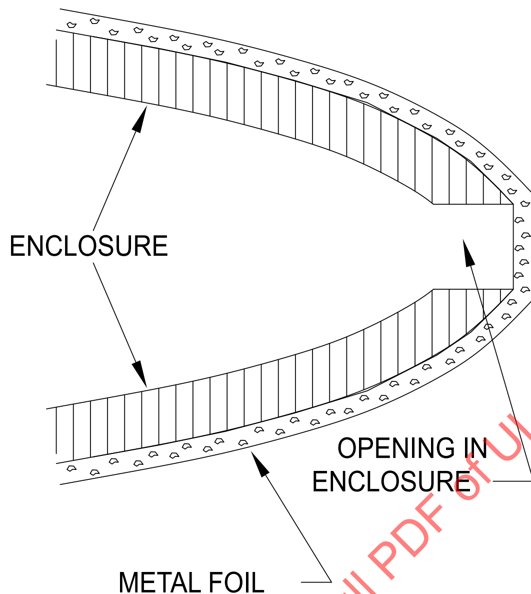
29.4 Semiconductors or similar electronic components liable to be damaged by application of the test voltage may be bypassed or disconnected for the test in 29.3.

29.5 The test voltage is to be applied between the hazardous voltage circuits of the UAS and non-current carrying conductive parts that may be accessible.

29.6 If the accessible parts of the UAS are covered with insulating material that may become live in the event of an insulation fault, then the test voltages are applied between each of the live parts and metal foil in contact with the accessible parts. The metal foil shall be wrapped tightly around and in intimate contact with the accessible part. The foil is to be drawn tightly across any opening in the enclosure or other accessible parts to form a flat plane across such opening. See Figure 29.1.

Figure 29.1

Method of covering enclosures with foil for measurement and tests



29.7 The test voltages shall be applied for a minimum of 1 min with the battery and/or cells disconnected to prevent charging during application of the voltage.

29.8 The test equipment shall consist of a 500 VA or larger capacity transformer, the output voltage, which is variable and which is essentially sinusoidal if using an ac test method and dc output if using a dc test method. There is no trip current setting for the test equipment since the test is checking for insulation breakdown, which results in a large increase of current. Setting a trip current may result in a false failure of this test, as it may not be indicative of insulation breakdown.

29.9 With reference to 29.8, a 500 VA or larger capacity transformer need not be used if the transformer is provided with a voltmeter that directly measures the applied output potential.

29.10 There shall be no evidence of a dielectric breakdown (breakdown of insulation resulting in a short through insulation/arcing over electrical spacings) as evidenced by an appropriate signal from the dielectric withstand test equipment as a result of the applied test voltage. Corona discharge or a single momentary discharge is not regarded as a dielectric breakdown (i.e. insulation breakdown).

30 Isolation Resistance Test

30.1 This test is intended to determine that insulation of the UAS provides adequate isolation of hazardous voltage circuits from accessible conductive parts of the UAS and that the insulation is non-hygroscopic.

30.2 A UAS with accessible parts shall be subjected to an insulation resistance test between the positive terminal and accessible dead metal parts of a UAS. If the accessible parts of the UAS are covered with insulating material that may become live in the event of an insulation fault, then the test voltages are applied between each of the live parts and metal foil in contact with the accessible parts as shown in 29.6 and Figure 29.1.

30.3 The insulation resistance shall be measured after a 60-second application with a high resistance voltmeter using a 500 V dc potential applied for at least 1 min to the locations under test.

30.4 The test shall be repeated on a sample subjected to humidity conditioning for 48 h in air having a relative humidity of 88 ±2 % at a temperature of 32 ±2°C (90 ±4°F). Measurements shall be made with the sample still in the humidity chamber.

30.5 The measured insulation resistance between the positive terminals and accessible parts of the UAS shall be at least 50,000 Ω.

31 Capacitor Discharge Test

31.1 A UAS that is intended for connection to an ac supply and is provided with filtering capacitors, or other primary capacitors, rated in excess of 0.10 µF and connected between one side of the line and ground, or from line to line, shall be subjected to this test.

31.2 The device shall be connected to a supply source of maximum rated voltage at 60 Hz. A storage oscilloscope shall be connected across the point of disconnection of the supply.

31.3 The device is connected to the source of supply and energized. The power is then removed and the resulting discharge curve for the stored charge on capacitors is measured using a 100 MΩ probe, and captured on the oscilloscope. The voltage after one second shall be less than 42.4 V peak.

31.4 The test is to be repeated with all switches in all possible positions and combinations.

32 Abnormal Operation

32.1 General

32.1.1 A UAS shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons when subjected to the tests specified in 32.2 – 32.10. Separate samples are to be used for conducting each test, unless using a sample for more than one test is agreeable to by all concerned.

32.1.2 Following each test on UAS with hazardous operating voltages, a Dielectric Voltage Withstand Test, Section 29 is to be conducted.

32.1.3 During these tests the device is to be secured in place on a softwood surface covered with a white tissue paper and a single layer of cheesecloth is to be placed over the entire enclosure taking care to keep the cheesecloth clear of the propellers. The cheesecloth may need to be secured in place to prevent unintended intake into the propellers.

32.1.4 For UAS devices directly connected to the ac supply, the supply circuit is to have branch circuit overcurrent protection, the size of which equals 125 % of the input current rating (20 ampere minimum), except where this value does not correspond with the standard rating of a fuse or circuit breaker, the next higher standard device rating shall be used. The rated voltage and frequency are to be used for this test. For UAS devices that are not connected directly to the ac supply, the supply circuit to the external charger shall be as described. For all tests performed when the UAS battery is not charging, the inherent protective components associated with the supply of battery power are to remain in place.

32.1.5 Each test is to be continued until further change as a result of the test condition is reduced significantly. When an automatically reset protector functions during a test, the test is to be continued for 7 h. When a manual reset protector functions during a test, the test is to be continued until the protector is operated for 10 cycles using the minimum resetting time, and not faster than 10 cycles of operation per min. The following are examples of acceptable test terminations:

a) Opening or shorting of one or more components such as capacitors, diodes, resistors, solid state devices, printed wiring board traces, or similar devices, when the opening or shorting of the component terminates operation.

b) Opening of the intended branch circuit overcurrent protection device described in 32.1.4.

c) Opening of an internal fuse or other protective device.

32.2 Component faults

32.2.1 A component, such as a capacitor, diode, solid state device, resistor, or similar component, connected in the power pack are to be short- or open-circuited, any two terminals one at a time, during any condition of operation including in-flight operation. This test is not required where circuit analysis indicates that no other component or portion of the circuit is overloaded. At the end of each component fault condition, the power pack shall comply with the requirement in 32.1.1.

32.3 Relay and solenoid burnout

32.3.1 An electromagnetic relay or a solenoid having an open coil construction is to be tested by blocking the armature or the plunger in the de-energized position. The test shall be continued until constant temperatures are obtained or for 7 h maximum. The test results shall comply with 32.1.1.

32.4 Disconnected fans/blocked vents

32.4.1 A device having forced ventilation is to be operated with the fan disconnected. For a device having more than one fan, the test is to be conducted with each fan disconnected, one at a time, or with two or more fans disconnected, if they are controlled or powered by the same connection. If part of the circuitry senses a disconnected fan and shuts down the unit, the circuitry shall be bypassed to allow operation with the fans disconnected or the circuitry shall be evaluated for suitability of this protective function.

32.4.2 The tests shall also be performed with ventilation openings for allowing air flow to cool internal components blocked, and the unit shall be operated at maximum normal load. If fans are provided for forced ventilation, the fans shall remain operational with the vents blocked. The test shall be continued until constant temperatures are obtained or for 7 h maximum. During the test, the UAS shall comply with 32.1.1.

32.5 Internal battery reverse polarity

32.5.1 For UASs with removable internal batteries that are not keyed or otherwise prevented from being connected incorrectly, the test in 32.5.2 is carried out and the UAS shall comply with 32.1.1.

32.5.2 During this test, fuses and other protective devices provided as part of the UAS are to remain in the device. Two samples are to be tested. The first sample is tested by connecting a fully discharged internal battery in reverse polarity and then attempting to charge the internal battery with a normal charging cycle. The second sample is tested by connecting a fully charged internal battery in reverse polarity and then attempting to use the UAS under the conditions of maximum normal load. In both cases, the test is to be continued until the internal protection operates or constant temperatures are obtained.

When an automatically reset protector or a manually reset protector ends the test, the test is to be continued as indicated in 32.1.5.

32.6 Overcharge

32.6.1 This test is intended to evaluate a UAS's electrical system's ability to withstand an overcharge condition under a single fault in the charging control circuitry that could result in an overcharge condition. One sample is to be tested for each fault condition applied. The same sample can be used for more than one test if it remains functional after a fault is removed. For battery packs in compliance with 17.3.2(a) or 17.3.2(b) this test is not required.

32.6.2 The sample with a fully charged battery is to be discharged at a constant discharge rate of 0.2 times the manufacturer’s rated capacity of the battery, or a higher discharge rate permitted by the manufacturer to the manufacturer's specified EODV. The sample is then subjected to a constant current charging at the manufacturer's specified charging rate (i.e. based upon the maximum intended charger output current rate) under a single fault condition in the charging protection circuitry that could lead to an overcharge condition. Protective devices that have been determined reliable may remain in the circuit as noted in 24.5. For information purposes, temperatures are to be monitored on the cell/module where temperatures may be highest. The output control circuitry of external chargers with standardized output connectors that may result in the use of unspecified chargers shall not be considered as a reliable control to prevent an overcharging condition.

32.6.3 The test is to be continued until the voltage has reached 110% of the maximum specified voltage limit and/or monitored temperatures return to ambient or steady state conditions and an additional 2 h has elapsed, or explosion/fire occurs. If the UAS's electrical system is operational after the test, it shall be subjected to a minimum of one charge/discharge cycle at the manufacturer's maximum specified values. The test shall be followed by an observation period per 24.7.

32.6.4 At the conclusion of the observation period, UAS samples that contain hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 29, or an Isolation Resistance Test, Section 30, (without humidity conditioning).

32.6.5 If a protective device in the circuit operates, the test is repeated at 90% of the trip point of the protection device or at some percentage of the trip point that allows charging for at least 10 min. Temperatures shall be measured on the cell/module where temperatures may be highest for monitoring purposes.

32.6.6 As a result of the overcharge test, there shall be no indication of any noncompliant results as outlined in Table 26.1. In addition, the voltage limits on the cells are not to exceed the specified upper limit charging voltage.

32.7 Short circuit

32.7.1 This test evaluates a UAS's electrical system’s ability to withstand a short circuit condition under a single fault in the charging control circuitry. For battery packs in compliance with 17.3.2(a) or 17.3.2(b) this test is not required.

32.7.2 A fully charged sample is to be short-circuited by connecting the positive and negative terminals of the sample with a circuit load having a total resistance of less than or equal to 20 mΩ.

32.7.3 Samples are to be subjected to a single fault across any protective device in the charging control circuit. Protective devices that have been determined reliable may remain in the circuit as noted in 24.5.

32.7.4 The sample shall be discharged until the sample has returned to ambient temperature or fire or explosion occurs. Temperatures shall be measured on the cell/module where temperatures may be highest for monitoring purposes.

32.7.5 If the UAS's electrical system is operational after the test, it shall be subjected to a minimum of one charge/discharge cycle at the manufacturer's maximum specified values. The test shall be followed by an observation period per 24.7.

32.7.6 If a protective device in the circuit operates, the test is repeated at 90% of the trip point of the protection device or at some percentage of the trip point that allows discharging for at least 10 min.

32.7.7 At the conclusion of the test and after cooling to near ambient, UAS samples that contain a hazardous operating voltage shall be subjected to a Dielectric Voltage Withstand Test, Section 29, or an Isolation Resistance Test, Section 30, (without humidity conditioning).

32.7.8 As a result of the Short Circuit test, there shall be no indication of any noncompliant results as outlined in Table 26.1.

32.8 Imbalanced charging

32.8.1 This test is to determine whether or not a UAS's electrical system with series connected cells can maintain the cells within their specified operating parameters if it becomes imbalanced. For battery packs in compliance with 17.3.2(a) or 17.3.2(b), this test is not required.

32.8.2 A fully charged battery pack of a UAS shall have all of its cells with the exception of one cell/cell block discharged to its specified fully discharged condition. The undischarged cells shall be discharged to approximately 50% of its specified state of charge (SOC) to create an imbalanced condition prior to charging.

32.8.3 The UAS's battery shall then be charged in accordance with the manufacturer's specifications using the specified charger. The voltage of the partially charged cells shall be monitored during the charging to determine if its voltage limits are exceeded. If the UAS's electrical system is operational after the test, it shall be subjected to a minimum of one charge/discharge cycle at the manufacturer's maximum specified values.

32.8.4 At the conclusion of the observation period, UAS samples that contain hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 29 or an Isolation Resistance Test, Section 30, (without humidity conditioning).

32.8.5 As a result of the test, there shall be no indication of any noncompliant results as outlined in Table 26.1.

32.9 Shock test

32.9.1 This test is intended to determine whether or not the UAS can withstand a mechanical shock that may occur when in use. For battery packs in compliance with 17.3.2(a) or 17.3.2(b), this test is not required.

32.9.2 The fully charged sample of the UAS electrical system is to be secured to the testing machine by means of a rigid mount, which supports all mounting surfaces of the sample. Temperatures on the center cell are monitored for information purposes.

32.9.3 The sample is to be subjected to mechanical shock testing with parameters as shown in Table 32.1 or according to a test profile determined by the customer and verified to the UAS application. The shocks are to be applied in all 6 spatial directions.

Table 32.1
Shock parameters

Maximum take-off weight	Pulse shape	Acceleration	Duration	Number of shocks
≤ 12 kg	half-sinusoidal	50 g	11 ms	3 ⊥ directions
> 12 ≤ 25 kg	–	25 g	15 ms	3 ⊥ directions

32.9.4 If the UAS's electrical system is operational after the test, it shall be subjected to a minimum of one charge/discharge cycle at the manufacturer's maximum specified values. The test shall be followed by an observation period per 24.7.

32.9.5 At the conclusion of the observation period, UAS samples that contain hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 29, or an Isolation Resistance Test, Section 30, (without humidity conditioning).

32.9.6 As a result of the test, there shall be no indication of any noncompliant results as outlined in Table 26.1.

32.10 Thermal cycling

32.10.1 This test determines the UAS's electrical system's ability to withstand exposure to rapidly changing environments such as when the UAS is entering or exiting a heated storage facility after being in a cold environment, changing temperatures during transport or storage outdoors, and the like, without evidence of damage that could lead to a hazardous event.

32.10.2 A fully charged UAS battery shall be subjected to the thermal cycling in accordance with 32.10.3. For battery packs in compliance with 17.3.2(a) or 17.3.2(b), this test is not required.

32.10.3 For the test, the UAS shall be placed in a chamber with ambient air cycling at the temperature extremes of the manufacturer's recommended operating ambient range as indicated in 7.2, or at the rated storage temperature, whichever is greater. The transition rate between exposure temperatures is to be 5°C (9°F)/min. Alternatively, samples may be moved between two chambers at the two test temperatures. The sample shall remain at each temperature extreme for as long as required for the sample to reach a uniform temperature (±5°C) of the chamber temperature but no less than 6 h. A total of five cycles (at the high and low temperature extremes) are to be performed.

32.10.4 If the UAS's electrical system is operational after the test, it shall be allowed to return to room ambient and then subjected to a minimum of one charge/discharge cycle at the manufacturer's maximum specified values. The test shall be followed by an observation period per 24.7.

32.10.5 At the conclusion of the observation period, UAS samples that contain hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 29, or an Isolation Resistance Test, Section 30, (without humidity conditioning).

32.10.6 As a result of this test, there shall be no indication of any noncompliant results as outlined in Table 26.1.

33 Vibration Test

33.1 Batteries/battery packs

33.1.1 This test evaluates the UAS's battery pack's ability to withstand vibration. The test shall be performed in accordance with the Standard for Environmental Testing – Part 2-64: Tests – Test Fh: Vibration, Broadband Random and Guidance, IEC 60068-2-64 per Table 6 of the Standard for Batteries for Use in Light Electric Vehicle (LEV) Applications, UL 2271 and CAN/ULC-S2271. For battery packs in compliance with 17.3.2(a) or 17.3.2(b), this test is not required.

33.1.2 The battery pack, or the complete UAS with the battery installed, is to be securely mounted to a vibration test platform in a manner similar to how it is oriented during use. The sample is to be subjected to a random vibration along three perpendicular axes in space in a sequence starting with the vertical axes (Z) and ending with the longitudinal axis (X).

33.1.3 The sample shall be subjected to the vibration in each axis for 21 h. For each axis the frequency shall be varied from 5 Hz to 200 Hz with power spectral density (PSD) for the vertical (Z) axis, the longitudinal (X) axis, and the transverse (Y) axis as outlined in the Standard for Electrically Propelled Road Vehicles – Test Specification for Lithium-Ion Traction Battery Packs and Systems – Part 1: High-Power Applications, ISO 12405-1.

33.1.4 If the UAS battery pack is operational after the test, it shall be subjected to a minimum of one charge/discharge cycle at the manufacturer's maximum specified values.

33.1.5 The test shall be followed by an observation period per 24.7.

33.1.6 At the conclusion of the observation period, UAS samples that contain hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 29, or an Isolation Resistance Test, Section 30, (without humidity conditioning).

33.1.7 As a result of the test, there shall be no indication of any noncompliant results as outlined in Table 26.1.

33.2 Complete UAS

33.2.1 A sample of the complete UAS shall not emit flame or molten metal or result in a risk of fire, electric shock, or injury to persons when subjected to the tests specified in 33.2.2 – 33.2.6.

33.2.2 The sample shall be mounted to the vibration fixture in a manner similar to how it is oriented during use. After the unit is subjected to the vibration test described in 33.2.3:

a) The UAS shall comply with the requirements in 33.2.1;

b) There shall be no loosening of parts; and

c) The UAS shall operate normally.

33.2.3 The vibration test shall consist of vibration for 1 h at a frequency of 10 to 55 Hz and back to 10 Hz, with a linear sweep having a sweep time of 2 min per sweep cycle. The amplitude shall be 1.0 +0.1, −0 mm (0.040 +0.004, −0 inch) p-p displacement limit in a vertical plane.

33.2.4 After this test, the sample shall be subjected to a minimum of one charge/discharge cycle at the manufacturer's maximum specified values. After this charge/discharge cycle, the sample shall be subjected to an observation period per 24.7.