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Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS)[1]

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1. Scope

1.1 This standard defines the requirements for batteries used in small Unmanned Aircraft Systems (sUAS).

1.2 This standard does not define requirements for the systems in which sUAS battery packs may be utilized.

1.3 This standard is subordinate to Specification F2910.

1.4 If allowed by a nation's GAA, certain sUAS may be exempt from this standard and may use commercial off-the-shelf (COTS) batteries in non-safety-critical payloads (lithium chemistries may not be exempted). Air transport regulations still shall be adhered to when air transport is used for COTS cells or batteries in bulk.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F2910 Specification for Design, Construction, and Test of a Small Unmanned Aircraft System (sUAS)

2.2 *Other Standards:*

ANSI/ASQ Z1.4-2008 Sampling Procedures and Tables for Inspection by Attributes[3]

UL 1642 Standard for Lithium Batteries[4]

3. Terminology

3.1 *Definitions and Acronyms*—The standard terminology for sUAS as defined in higher level standards applies in general to this standard except as noted below.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *C-rating, n*—maximum steady-state current (amps) at which the battery cell or pack may be discharged without having pack temperature exceed the CTT of its constituent cell(s) or result in a reduction in cell life. C-rating is expressed as a multiple of the capacity. For example, a battery with a nominal capacity of 4 Ah may have a C-rating of 5C, meaning that 20 A would be considered its maximum safe current.

3.2.2 *characteristic thermal threshold, CTT, n*—the temperature beyond which a rechargeable battery cell of particular chemistry and structure will exhibit permanent deterioration of its critical performance parameters as evident upon subsequent charge/discharge cycles. Cell capacity and internal resistance are critical performance parameters. CTT is rated at both upper and lower thresholds.

3.2.3 *depth of discharge, DOD, n*—ratio of cell or pack capacity expended relative to its nominal capacity.

3.2.4 *pack, n*—a single cell or composition of battery cells connected in series or in parallel or both plus monitoring electronics, structure, and connector(s).

3.2.5 *pack assembler, n*—that supplier which performs the manufacturing processes that integrate the essential components into a functional pack. In the event that multiple suppliers are involved in the assembly process, the pack assembler is the supplier that performs the final electrical connection(s). One supplier may weld solderable tabs to a batch of cells, a second supplier may connect circuitry, wiring and a connector, and yet a third may install the assembly in a plastic housing. In this example, the second supplier would be the pack assembler.

3.2.6 *shall versus should versus may, v*—use of the word "shall" implies that a procedure or statement is mandatory and must be followed to comply with this standard, "should" implies recommended, and "may" implies optional at the discretion of the supplier, manufacturer, or operator. Since "shall" statements are requirements, they include sufficient detail needed to define compliance (for example, threshold

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society for Quality (ASQ), 600 N. Plankinton Ave., Milwaukee, WI 53203, http://www.asq.org.

[4] Applicable only to 5.1 on cell suppliers.

Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.

values, test methods, oversight, reference to other standards). "Should" statement are provided as guidance toward the overall goal of improving safety and could include only subjective statements. "Should" statements also represent parameters that could be used in safety evaluations and could lead to development of future requirements. "May" statements are provided to clarify acceptability of a specific item or practice and offer options for satisfying requirements.

3.2.7 *small unmanned aircraft system, sUAS, n*—composed of the small unmanned aircraft (sUA) and all required on-board subsystems, payload, control station, other required off-board subsystems, any required launch and recovery equipment, and command and control (C2) links between the sUA and the control station. Since any one of the preceding subsystems may affect reliability and thus safety of the sUAS, batteries used in those subsystems shall comply with this standard unless failure of the battery will not compromise safety. For purposes of this standard sUAS is synonymous with small Remotely Piloted Aircraft System (sRPAS), and SUA is synonymous with a small Remotely Piloted Aircraft (sRPA).

3.2.8 *supplier, n*—any entity engaged in the design or production of a battery pack or any component of a pack intended for use in a sUAS. The *cell supplier* is the manufacturer of the fundamental cell(s) constituent in a battery core. Various suppliers contribute to the production of a pack, and any differences between them are described both explicitly and by context throughout the document.

3.3 *Acronyms:*

3.3.1 *COTS*—Commercial off the Shelf

3.3.2 *CTT*—Characteristic Thermal Threshold

3.3.3 *DOD*—Depth of Discharge

3.3.4 *IC*—Internal Combustion

3.3.5 *Li*—Lithium

3.3.6 *LiFe*—Lithium Ferrite (commonly used, abbreviated reference to $LiFePO_4$)

3.3.7 *$LiFePO_4$*—Lithium Iron Phosphate

3.3.8 *LiIon*—Lithium Ion

3.3.9 *LiPo*—Lithium Polymer (commonly used term for a package-specific variation of the Lithium Ion chemistry)

3.3.10 *MSDS*—Material Safety Data Sheet

3.3.11 *NiCd*—Nickel Cadmium

3.3.12 *NiMH*—Nickel Metal Hydride

3.3.13 *PCM*—Protective Circuit Module

3.3.14 *PVC*—Polyvinyl Chloride

3.3.15 *SDS*—Safety Data Sheet

3.3.16 *SLA*—Sealed Lead Acid

3.3.17 *sUAS*—Small Unmanned Aircraft System

3.3.18 *UAS*—Unmanned Aircraft System

3.3.19 *UN-GHS*—United Nations Global Harmonization System

4. Applicability

4.1 This standard relates to and is referenced by other sUAS standards at the sUAS system level as listed in Section 2. This standard is mandatory at any point in the sUAS system in which batteries are used, except for payload downlinks that have no effect on flight safety.

4.2 This standard is written for all sUAS that are permitted to operate over a defined area and in airspace defined by a nation's GAA. Unless otherwise specified by a nation's GAA, this standard applies only to UA that have a maximum takeoff gross weight of 55 lb/25 kg.

4.3 Criticality of this standard is derived from safety risk analysis. The following failures are critical and are listed hierarchically, the first being the most critical:

4.3.1 Loss of independent power for flight termination by any means requiring battery power, resulting in inability to terminate the flight safely;

4.3.2 Failure of primary power for the FCS resulting in loss of control to permit safe flight or recovery;

4.3.3 Failure of ignition power (if a battery is utilized instead of a magneto, alternator, generator or the like for internal combustion) or primary power for electric propulsion, creating the inability to return the sUAS to base and creating a ground impact hazard.

5. Cells

5.1 *Responsibility of Cell Suppliers*—As a minimum, the cell supplier shall possess and provide the following:

5.1.1 *Process Control Plan* for the specific cell being provided, including *Quality Control Procedures* and *Recording Methods*.

5.1.2 A *Quality Assurance Plan* for the specific cell being provided, including compliance with UL 1642 requirements for cells.

5.1.3 *MSDS*, also known as SDS per the UN-GHS for chemicals classification.

5.1.4 *Technical Data Sheet* shall be a formal document, not preliminary or informal. The manufacturer's datasheet shall include specification of the upper CTT.

5.1.5 Every cell shall be marked with its *Lot Number* and *Supplier's Name* to aid failure analysis, facilitate traceability, and minimize the extent of a recall should such action become necessary.

5.2 *Responsibility of Pack Assembler:*

5.2.1 *Lot Testing*—A sample from each lot of cells shall be subjected to capacity testing and physical inspections. The capacity test and physical inspections may, but are not required to be performed on the same cells. Sampling shall be in accordance with ANSI/ASQ Z1.4-2008. Any alternate plan must be approved by the GAA. The sampling plan shall accept on zero defects.

5.2.1.1 *Capacity Test*—The sample shall undergo one complete charge-discharge cycle to verify the integrity of the lot. A charge-discharge cycle is defined as a full charge followed by a full discharge to the depth specified by the cell manufacturer or as typical for the subject chemistry.

5.2.1.2 *Physical Inspection*—Physical inspections shall be performed on the sample. A subject cell is to be rejected for any of the following conditions:

(1) Swelling;

(2) Electrolyte leakage;

(3) Out-gassing;

(4) Odor, even in the absence of visible electrolyte leakage, an obvious odor shall be considered evidence of a deteriorated cell;

(5) Deformed or damaged casing;

(6) Punctures;

(7) Tab condition—Seals are to be undamaged, and welds are to be unbroken and of satisfactory quality. If a cell is supplied with a PCM connected, accessible solder connections to the tabs shall also be inspected. If a solder connection is unacceptable, it may be reworked by the pack assembler.

5.2.2 *Received-Voltage Test*—The pack assembler shall measure this voltage on every cell in the lot. The measurement shall be made before any load or charge has been applied to the cell. The measurement is taken directly at the cell tab, bypassing any protection circuitry that may be connected. In the event that a cell's received voltage is outside limits that are normal or recoverable for the particular chemistry, the cell shall be rejected. The received voltage shall not vary significantly from what is considered the typical chemistry-specific storage/shipping voltage or the mean measurement for the bulk of the lot. The received voltage for a lot will typically vary little from cell to cell and certainly should remain within a 10 % window. (For example, a LiPo will normally be shipped in a half-charge state, holding at about 3.8 V). If the cell is outside the storage/shipping voltage, the cell shall undergo the capacity test and physical inspections of 5.2.1 to ensure its integrity. The received-voltage test may be performed as part of the assembly process rather than as an incoming test if the lot will be utilized for production before significant self-discharge occurs.

5.2.3 *Records and Certifications*—The pack assembler shall obtain and make available to the GAA and the procuring entity pertinent information regarding the pack assembly. These data shall be available so long as that pack model is marketed or sold and for a minimum of three years thereafter. These data shall either be shipped with the pack(s), provided upon request or be accessible by other means such as the pack assembler's website:

5.2.3.1 *The technical data sheet from the cell supplier for cells used in the pack*;

5.2.3.2 *The MSDS (also known as SDS per the UN-GHS for chemicals classification) for the cell type used in the pack*;

5.2.3.3 *The data items, by lot*, listed under 5.1.3 – 5.1.5 (that is, the pack assembler is to carry forward the data provided by the cell supplier);

5.2.3.4 *Pack assembler's specified shipping/storage voltage*—These data are not intended to be a record of measured voltage for each pack but to stipulate the voltage range that the procuring entity can expect to measure upon receipt of a pack for the particular chemistry;

5.2.3.5 *The lot number of constituent cells used in a pack traceable to the pack serial number*;

5.2.3.6 *Date of manufacture of the pack*—As defined in Section 6, the date may be codified in the serial number.

5.2.4 *Pack Assembly Requirements*—A multi-cell pack shall not contain cells from more than one lot. An exception may be made if three conditions are met: *(1)* the date of manufacture of the cells are within a six-month span; *(2)* all cells to be used in the pack are tested for capacity and found to be within 5 % of each other; and *(3)* all of the cells were manufactured recently enough to be considered acceptable for use in new construction for the particular chemistry.

5.2.5 *Final Test*—As a minimum, each completed pack shall be subjected to two charge-discharge cycles, following which the pack shall be charged to its appropriate, chemistry-specific shipping/storage voltage. A charge-discharge cycle is defined as a full charge followed by a full discharge to the depth specified by the cell manufacturer or as typical for the subject chemistry. The pack shall demonstrate its rated capacity by means of this testing to be acceptable for delivery to the procuring entity.

6. Mechanical Design and Assembly

6.1 *In-Process Quality*—The assembly process shall be devised such that it is conducive to observation of the physical conditions listed in 5.2.1.2. This requirement does not stipulate inspection of cells beyond lot testing but rather is intended to maximize exposure of the cells to visual scrutiny during assembly.

6.2 *Cell Connections*—Cells shall be interconnected using techniques that minimize failure caused by vibration and impact. If tab-to-tab connection of individual cells is used to form a pack, the connection shall be resistance-welded to the individual cell terminal. If cells are interconnected using double-sided printed circuit connecting boards, these boards shall have plated-through tab slots or holes.

6.3 *Wiring*—All power and cell-sensing wiring shall be strain relieved at the junction with the cell or interconnect tabs and secured at a point before exiting the pack.

6.4 *Vibration*—The pack assembly may be surrounded with impact and vibration-absorbent material such that the assembled pack meets governing-body requirements for shipment by air.

6.5 *Puncture Resistance*—An assembled pack having one or more non-rigid cells shall be housed in a protective material that provides resistance to mechanical penetration beyond that of the bare, unprotected cell. LiPo cells are one such example of a non-rigid cell and shall as a minimum be sheathed in a conforming PVC wrap or other similar material. Other means of housing non-rigid cells, such as a plastic or metal casing may be employed. If the pack is being designed for a specific system, the required protection shall be defined at the system level, taking into consideration the form of propulsion (IC or electric) and whether the sUAS will be carried on another aircraft for launch.

6.6 *Identification*—Pack identification is required as follows:

6.6.1 *Supplier*—The pack assembler defined in 3.2.5 shall be identified by name on the pack (a company logo is not sufficient labeling);

6.6.2 *Capacity*—The pack capacity, rendered in Amp-hours (Ah) or milli-Amp-hours (mAh) shall be stated on the pack.

6.6.3 *Serialization*—The pack assembler shall serialize the final pack assembly and maintain records that correlate cell lot number with battery pack serial number (see 5.2.3.5). Records shall also identify the date of manufacture of the pack assembly. A serial number that contains a date code is an acceptable means of documenting the date (for example, YYMMXXXX, YYWWXXXX).

6.6.4 *Safety Warnings*—Appropriate safety warnings particular to the battery chemistry shall be affixed to the pack. In the case of packs too small or otherwise unable to accommodate all such warnings, the information may appear on the smallest quantity container in which the pack(s) are shipped. The following shows an example of a typical warning label for a lithium battery:

CAUTION:
DO NOT DISPOSE OF IN FIRE
DO NOT HEAT ABOVE 60C (140F)
DO NOT DISASSEMBLE
DO NOT PUNCTURE OR CRUSH
DO NOT ALLOW TERMINALS TO SHORT
SEE OWNER'S MANUAL FOR ADDITIONAL DETAILS

6.6.5 *Recovery Identification*—The outer pack enclosure or larger portion thereof shall by some means be yellow in color to provide easy identification at a crash site. Some portion of the yellow coloring shall be discernible when viewed from any angle.

7. Electrical Design

7.1 Cells used for sUAS are anticipated to be NiCd, NiMH, LiIon, LiFe, $LiFePO_4$, LiPo, or SLA. The use of any of these chemistries is anticipated in applications in which primary power is an IC engine. Electric propulsion systems are likely to use LiIon, LiFe, or LiPo cells because of the demand for superior power density. Vented lead acid cells shall not be used in sUAS. The electrical design and performance criteria are as follows:

7.1.1 *Capacity*—The capacity stated on the pack label is to be based either on the typical capacity of a newly manufactured pack or that of a "broken-in" pack, *whichever is less*. The "broken-in" capacity is defined as the typical capacity observed at the flattest portion of the life-cycle curve for the pack. Data on the broken-in capacity of constituent cells may be used to aid in determining the broken-in capacity of a new pack design if these data exist. The pack designer shall perform the testing and research on the pack design necessary to ascertain capacity before stating it on pack marking or by other means of advertising. The capacity test should be done under lab conditions of 25C, ambient humidity and no forced cooling. The capacity of any pack that carries a nominal claimed capacity should be within 1 Sigma of the nominal capacity so stated in which the statistical sample is 100%.

7.1.2 *Charge*—Before storage or shipping from the pack assembler, the pack shall be charged/discharged to a level that is optimal for transport and long-term storage for the particular chemistry.

7.1.3 *Wiring*—Wiring used shall be of sufficient gauge and capacity that the wire temperature does not exceed the thermal rating of the insulation type during highest normal expected load.

7.1.4 *Connectors*—Any connector that is part of the pack assembly shall conform to the following criteria:

7.1.4.1 *Contacts*—Connector contacts shall be gold-plated or otherwise treated to optimize conductivity and to aid in the prevention of oxidation or corrosion. Contact resistance shall be low enough that the connector body temperature does not exceed temperatures that would cause failure of the connector materials or pose other hazards to the pack under the highest normal expected load during discharge.

7.1.4.2 *Configuration*—The connector may include heavy-duty pins for power and smaller pins for the cell-balance nodes in packs with series-connected cells. If single pins are used for main power and return lines, the pin itself shall have multiple points of contact (at least two) to preclude power failure as a result of loss of a single point of contact. Alternatively, the use of multiple single-point pins may be employed to satisfy the need for redundancy.

7.1.4.3 *Non-Electrical Materials*—Connectors shall be selected having housing material that is rated to withstand temperatures at which the particular cell chemistry can operate safely.

7.1.5 *Node Access*—The design shall provide connector access to the nodes between individual serial sub-packs or cells. Charge of pack end-to-end voltage alone is not satisfactory; the intra-cell nodes in any pack with series-connected cells shall be accessible to facilitate monitoring of overcharge conditions. Even if a pack design includes integrated cell-balancing, a node access connector shall still be included to facilitate a sUAS which might monitor node voltages for safety purposes. Alternatively, a pack with integrated cell-balancing or other self-monitoring circuitry may provide the node voltage or other sufficient health information through a data bus rather than a node access connector.

7.1.6 *Thermal Performance*—Life cycle and cell capacity deteriorate when a cell reaches temperatures beyond the characteristic thermal threshold (CTT) specific to the particular chemistry. In the case of lithium chemistries, as an example, the upper CTT has been found to be 140°F (60°C). The battery pack shall therefore be designed to minimize internal heat generation during operational discharge. Effects of cell internal resistance, tab resistance and pack capacity should be considered in combination when evaluating their effect on self-heating. If a continuous discharge current is to be specified or advertised for the pack, that rating is to be for operation at no greater than the CTT of its constituent cells. Performance to this criteria shall be validated and recorded by the pack designer or other supplier's operational testing.

8. Maintenance

8.1 Maintenance of the pack and the recording of maintenance data is the responsibility of the user. The pack chemistry and demands of the application determine the frequency of periodic testing required to evaluate the performance of the pack throughout its life cycle. The designer of the sUAS system shall perform a reasonable amount of testing to determine this frequency and the minimum capacity that is required for the pack to be deemed flight-worthy.

8.1.1 *Charging*—Charging systems designed for the specific battery chemistry shall be used. Multi-chemistry chargers are acceptable but shall be programmed such that the specific pack chemistry is charged accordingly.

8.1.1.1 *Series-Cell Balancing (Lithium Chemistries)*—All Li batteries shall be charged using equipment that provides precise balance charging. Alternatively, a conventional bipolar charger may be used if the pack has integrated cell-balancing circuitry. For added safety, charging may be done in a flame- and explosion-resistant enclosure.

8.1.1.2 *Temperature Change (Lithium Chemistries)*—A decrease in capacity of a lithium cell can result from receiving a charge at low temperatures or from temperature decrease following a full charge cycle. A lithium pack should therefore be subjected to a load or protected from significant temperature decrease after receiving a full charge. To further aid in mitigation of this risk, the charging system should test the battery condition before charge, adjust for ambient temperature and provide recording and diagnostics for all charges.

8.1.1.3 *Physical Inspection*—Prior to charging, every pack shall be inspected per the criteria established by 8.1.4. If no defects are found the pack may be charged.

8.1.2 *Routine Evaluation*—Pack capacity should be measured and recorded once each 100 cycles during normal operations. The following provide guidance for the service-life of a pack:

8.1.2.1 *Test Marking*—As a minimum, the recording of data obtained by periodic testing should be implemented by labeling the individual pack with its capacity and the date on which it was tested.

8.1.2.2 *High Utilization*—In an environment in which operations regularly require DOD exceeding 80 %, additional emphasis should be placed on periodic maintenance to ensure that adequate capacity is retained.

8.1.2.3 *Low Utilization*—Pack capacity should be validated and the data recorded in a battery log at any time a pack is utilized after storage for a period of three months or more.

8.1.2.4 *Service Limit*—Packs that have lost 20% of their rated capacity should be removed from service.

8.1.3 *Storage*—The pack shall be charged/discharged to a level that is optimal for storage based on the particular chemistry. All Li packs should be stored at approximately one-half capacity or at the supplier-specified charge level for long term storage any time a pack is out of service for more than one month.

NOTE 1—Most Li chemistries have very low self-discharge rates (depending on the current draw of any integral circuitry), but are susceptible to degradation if subjected to temperature decrease when left fully charged. Other chemistries have self-discharge rates that require that the pack be either float-charged periodically or charged cyclically once each month of storage. Recommendations provided by the supplier should be followed.

8.1.4 *Damage Evaluation*—A pack that has been involved in a crash or any event that has resulted in physical damage shall be evaluated to determine if it must be disposed of or if it is repairable and fit to return to service.

8.1.4.1 *Disposal*—The pack shall be disposed of if any of the following conditions are observed:

(1) Electrolyte leakage;

(2) Odor (even in the absence of visible damage, an obvious odor shall be considered evidence of a deteriorated pack);

(3) Punctured or crushed casing;

(4) Severe swelling (moderate swelling in LiPo packs is typical and not cause for disposal);

(5) Mechanically stressed electrical connector.

8.1.4.2 *Return to Service*—To be deemed fit for service; the pack shall be subjected to a complete charge/discharge cycle to verify its capacity is within the service limit per 8.1.2.4. A permanent record of the pack, identified by serial number shall be created describing the damage, the date of the incident and any repairs made.

9. Keywords

9.1 small unmanned aircraft system battery; sUAS system battery