Standard Practice for Design and Manufacture of Electric Propulsion Units for Light Sport Aircraft[1]

This standard is issued under the fixed designation F2840; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers minimum requirements for the design and manufacture of Electric Propulsion Units (EPU) for light sport aircraft, VFR use. The EPU shall as a minimum consist of the electric motor, associated controllers, disconnects and wiring, an Energy Storage Device (ESD) such as a battery or capacitor, or both, and EPU monitoring gauges and meters. Optional onboard charging devices, in-flight charging devices or other technology may be included.

1.2 *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]

F2245 Specification for Design and Performance of a Light Sport Airplane

F2972 Specification for Light Sport Aircraft Manufacturer's Quality Assurance System

2.2 *Other Standards:*

EASA CRI F-58 Lithium Battery Installations[3]

SAE J2344 Guidelines for Electric Vehicle Safety[4]

3. Significance and Use

3.1 This specification provides designers and manufacturers of electric propulsion for light sport aircraft design references and criteria to use in designing and manufacturing EPUs.

3.2 Declaration of compliance is based on testing and documentation during the design, ground testing and flight testing of the EPU by the manufacturer or under the manufacturers' guidance.

3.3 Manufacturers of the EPUs are encouraged to review and incorporate appropriate standards and lessons learned from ground based systems as documented in SAE J2344 and EASA CRI F-58 (see Appendix X2).

3.4 Electric aircraft may contain potentially hazardous level of electrical voltage or current. It is important to protect persons from exposure to this hazard. Under normal operating conditions, adequate electrical isolation is achieved through physical separation means such as the use of insulated wire, enclosures, or other barriers to direct contact. There are conditions or events that can occur outside normal operation that can cause this protection to be degraded. Some means should be provided to detect degraded isolation or ground fault. In addition, processes or hardware, or both, should be provided to allow for controlled access to the high voltage system for maintenance or repair. A number of alternative means may be used to achieve these electrical safety goals including automatic hazardous voltage disconnects, manual disconnects, interlock systems, special tools and grounding. The intention of all these means is either to prevent inadvertent contact with hazardous voltages or to prevent damage or injury from the uncontrolled release of electric energy. Lightning strikes are not addressed in this Standard Practice because LSA aircraft are limited to VMC flight only.

4. Electric Propulsion Unit (EPU) Model Designation

4.1 *Electric Propulsion Parts List*—A detailed parts list is required for each electric propulsion unit qualified in accordance with this specification.

4.2 *New Electric Propulsion Unit Model Designations:*

4.2.1 Each new EPU must be qualified in accordance with this practice.

4.2.2 Design or configuration changes that impact the installation interface, performance, or operability of the EPU require a new EPU model designation.

4.3 *Design Changes of Parts*—Each design change of a part or component of an EPU model qualified to this specification shall be evaluated to the requirements of this specification.

[1] This practice is under the jurisdiction of ASTM Committee F37 on Light Sport Aircraft and is the direct responsibility of Subcommittee F37.20 on Airplane.

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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 European Aviation Safety Agency (EASA), Postfach 10 12 53, D-50452 Koeln, Germany, http://easa.europa.eu/home.php.

[4] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

5. Data Requirements

5.1 *Retained Data*—The following data and information shall be retained on file at the manufacturer's facility or alternative business entity for a minimum of 18 years after production is discontinued.

5.1.1 Drawings, reference specifications and other technical data that define the EPU configuration.

5.1.2 Primary material and process (M&P) specifications in effect at the time of Declaration of Compliance and referenced in the parts drawings. Second tier, flow down M&P documents are not required to be retained.

5.1.3 Engineering analyses and test data prepared for qualification with this specification.

5.2 *Delivered Data*—The following data shall be delivered to the airplane manufacturer to support design and operation of the applicable airplane.

5.2.1 An EPU performance specification that defines the system performance under all anticipated operating environments.

5.2.2 An installation manual that defines all functional and physical interface requirements of the EPU. This should include an EPU installation drawing.

5.2.3 Detailed specifications for any caution or warnings that must be placed on the aircraft. The warnings shall ensure that operators, maintenance crews, and emergency crews understand potential hazards with the electric propulsion system.

5.2.4 An operating manual that defines normal and abnormal operating procedures and any applicable operating limitations, including EPU and any aircraft limitations.

5.2.5 A maintenance manual that defines periodic installed maintenance, major inspections, replacement or overhaul intervals, and any other maintenance limitations including limited life components requiring replacement between overhaul intervals. Maintenance requirements for the continued airworthiness of the EPU shall be specified. This manual shall identify any special equipment or testing required to ensure the electric propulsion system is safe for continued operation.

5.2.6 An overhaul manual that provides instructions for disassembling, replacing or overhauling components identified in the manual for such, in order to return the EPU to airworthy condition that is safe for operation until the next major overhaul.

6. Design Criteria

6.1 *Materials*—The materials and components used in the EPU must be adequate for the intended design conditions of the system.

6.2 *Fire and Electric Shock Prevention*—The design and construction of the EPU shall minimize the probability of the occurrence and spread of fire and electric shock. The design shall incorporate electrical isolation-insulation materials capable of shielding the occupants and ground personnel from electrical shock in the event of an in flight or ground based emergency. Wire insulation subject to arc tracking, such as Kapton™, shall not be used. Isolation means the electrical resistance between the battery high voltage system and any airframe conductive structure. A value greater than or equal to 500 ohms/volt at the maximum working voltage is defined as isolated. As a minimum, the system shall:

6.2.1 Incorporate a non-resettable fuse as part of the energy storage device which protects the main power lead wires from an over-temperature or over-current condition. A warning or indication device to alert the pilot shall be incorporated.

6.2.2 Incorporate a pilot/mechanic operated main shutoff of the energy storage device from the remainder of the EPU system. This shutoff shall not rely on any processor or software actions to provide electrical isolation of the energy storage device.

6.2.3 Incorporate an ESD which is electrically isolated from the airframe.

6.2.4 Consider incorporation of a ground fault detection system that provides the pilot or ground personnel a warning if the airframe is no longer fully electrically isolated from the energy storage device.

6.2.5 Be designed for flight in (or flight subsequent to exposure to) heavy rain without risk to occupants or ground personnel.

6.2.6 Incorporate warnings, cautions or placards on components and on the airframe exterior conveying the potential high voltage hazards.

6.2.7 Develop maintenance procedures enabling continuous airworthiness with minimal risk to mechanics or ground personnel.

6.3 *Electrical Arcing*—The EPU shall be designed to eliminate the possibility of high voltage electrical arcing (or corona effect) at altitudes up to those specified as the maximum in the operating manual (see 5.2.4).

6.4 *Cooling*—The EPU must include provisions for cooling components as required for safe operation when operated within the operational limitations (see 5.2.4). Provisions must consider cooling requirements for all phases of flight (as a minimum take-off, climb, cruise, descent, and ground taxiing) at all power settings, and also ground operations at all power settings. As a minimum, the operating manual required in 5.2.4 must specify motor and energy storage device temperature limits. Cooling provisions for the energy storage device during charging must also be considered.

6.5 *Motor Mounting*—The motor and motor attach load factor requirements shall comply with the flight and emergency landing load factors of the applicable airframe specification, that is, Specification F2245, et al. Attach points on the motor must have data for the correct design of mounting structures to the airframe. The maximum allowable limit and ultimate loads for the motor mounting attachments and related structure must be specified.

6.6 *Energy Storage Device (ESD) Mounting*—The ESD-EPU manufacturer shall provide to the airframe manufacturer anticipated flight and emergency landing loads to be transferred to the airframe. Attach points on the ESD must have data for the correct design of mounting structures to the airframe. The maximum allowable limit and ultimate loads for the ESD mounting attachments and related structure must be specified.

6.7 *Processor Controlled Functions*—The EPU shall be designed such that it is tolerant of loss of non-essential functions without loss of power to the propeller. Electrical system components having the potential for instantaneous failure versus wear out mode shall be identified. A safety analysis of instantaneous failure modes on critical components shall be identified by a safety analysis and consideration be given for redundancy. Design consideration of EMI, environmental, HIRF, and software influences on the performance of digital and microprocessor controlled devices, shall be made.

6.8 *Pilot Controls*—The EPU shall have a throttle and other controls that are simple, non-confusing and intuitive.

6.9 *Low State of Charge Performance*—Any significant reductions in power with a "near empty" energy storage device or with an emergency "limp home" mode are acceptable provided they are documented in the operating manual (see 5.2.4) and the pilot is clearly informed of the limitation through the EPU instrumentation.

6.10 *Reliability*—Shall conform to the test described in 7.5.

6.11 *Vibration*—The EPU shall be designed and constructed so that it will operate throughout its normal operating range of propeller speeds and power without inducing excessive vibrations or stress in any of the EPU or airframe parts. EPU design consideration shall be given regarding vibrations-loads induced from ground operations, that is, rough field operations etc.

6.12 *Charger*—The EPU charging system shall be designed to safely enable ground personnel to recharge the energy storage device. As a minimum the system shall:

6.12.1 Be designed to prevent improper (reverse polarity) connections. Incorporate features such that if ground personnel leave the charging turned on for an extended period of time there is no safety risk to personal, facilities, or to the electric propulsion system.

6.12.2 Incorporate adequate ground fault protection of the charging system.

6.12.3 Incorporate features such that ground personnel can determine the state of charge of the energy storage device (ESD) prior to disconnecting the charger system from the charge source.

6.13 *Instrumentation*—The EPU shall incorporate instrumentation for providing the pilot status and warning of the operating system. As a minimum, the system shall:

6.13.1 Incorporate a "fuel gauge" which informs the pilot of the remaining energy in the energy storage device. The gauge as a minimum shall be intuitive to the pilot, preferably have a colored arc, color coded bars or similar warning system denoting minimum energy reserves and have a corresponding numerical readout showing energy remaining, utilizing internationally recognized units of measure.

6.13.2 Consider incorporation of a "recommended" warning light to inform the pilot that there is minimum energy left in the system.

6.13.3 Incorporate tachometer informing the pilot of the motor RPM and the maximum allowable motor RPM.

6.13.4 Incorporate temperature gauge for the motor informing the pilot of the motor temperature status and the maximum allowable temperature.

6.13.5 Incorporate a method to inform the pilot that the electric propulsion unit is in "run" mode.

6.13.6 Incorporate instrument warning lights to inform the pilot of any degraded performance modes or other safety issues.

7. Qualification Tests

7.1 *Calibration Test*—Each EPU design shall be tested and the characteristics of the system rated shaft power, speeds, electric power consumption and energy storage device capacity shall be determined.

7.2 *Energy Storage Device Charging Test*—Each EPU shall be tested to confirm that the (ESD) can be fully charged without incurring damage or degradation when charged by any source which the designer/manufacturer has specified for the system. During the specified testing, the electrical current at the source must be considered to be unlimited and the voltage to be the full range defined for the source. Additionally, the ESD shall be tested to determine the number of life cycles for which it is certified. The established cycle life shall be documented in the operating, maintenance, and overhaul manuals (see 5.2.2, 5.2.4 and 5.2.6).

7.3 *Durability Test*—Each EPU shall be subjected to a system test that will verify durability by one of the following methods:

7.3.1 *Accelerated Overhaul Test*—This test simulates an EPU overhaul interval. A protocol for this test shall incorporate, as a minimum, the following elements:

7.3.1.1 At least 100 % of the time at maximum power that would occur over the overhaul interval.

NOTE 1—For calculation, each hour of normal flight would have 5 minutes of full power.

7.3.1.2 At least 10 % of the time at cruise power that would occur over the overhaul interval.

7.3.1.3 At least one cycle per hour of test from maximum power to cruise power and back.

7.3.1.4 At least one system start for each 5 h of testing.

7.3.1.5 During testing the motor must be maintained within 20°F of the max continuous operating temperature. Motor loading shall take into account cooling flow of air to the motor, ambient temperature, and thermal rise after reduction in air flow during taxiing etc.

7.3.1.6 The EPU must be tested to simulate max thrust loads at the propeller.

7.3.1.7 Each accessory drive and mounting attachment (if any) must be loaded. During operation at maximum power, the load imposed by each accessory used only for an aircraft service must be the limit load specified by the applicant for the motor drive or attachment point.

7.3.1.8 Each electrical power port must be loaded. During operation at maximum power, the electrical load imposed on each electrical power port used only for an aircraft service must be the limit load specified by the applicant for the electrical power port.

7.3.1.9 After completing the accelerated overhaul test, each EPU must be completely disassembled and each component must conform to new or overhaul limits established by the designer/manufacturer specified in 5.2.6.

7.3.2 *Endurance Testing by Fleet Leader*—In place of the accelerated overhaul test in 7.3.1, the EPU may complete endurance flight testing.

7.3.2.1 The Fleet Leader Test Method is the operation of the make and model of the EPU being developed on a flying aircraft under the control of the EPU designer/manufacturer.

7.3.2.2 All maintenance of the electric propulsion system must be documented and shall be as defined in the maintenance manual required per 5.2.5. If any major component is replaced, other than those specified in the maintenance manual as limited life components requiring replacement between overhaul intervals, the endurance test shall restart at 0 h.

7.3.2.3 Periodic inspection must be performed. The flight test aircraft shall be flown and stored in humidity, temperature and density altitude conditions for which the manufacturer states the EPU may operate under in the operating manual (see 5.2.4).

7.3.2.4 The EPU must be tested to simulate max thrust loads at the propeller.

7.3.2.5 Each mechanical accessory drive or electrical power accessory connector must be loaded to that limit load specified by the applicant.

7.3.2.6 After completing the endurance test, each EPU must be completely disassembled and each component must conform to new or overhaul limits established by the designer/manufacturer specified in 5.2.6.

7.4 *EPU Overhaul Interval*—The EPU overhaul interval shall be reported in the operations manual (see 5.2.4) as either the overhaul time used to complete the accelerated overhaul test in 7.3.1 or 80 % of the time accumulated on the EPU model fleet leader from 7.3.2.

7.5 *Reliability Test*—The intent of the requirement is that the aircraft operator of the electrically powered LSA aircraft shall not experience total power failures of the propulsion system at frequencies greater than that expected for the spark ignition internal combustion engine powered aircraft. Reduction or partial loss of power in a failure mode is acceptable provided operation in this mode is well documented in the operating manual (see 5.2.4) and the propulsion instrumentation provides appropriate warnings. Compliance with the requirement shall be accomplished by one of the following methods:

7.5.1 *Reliability Testing by Demonstration*—An acceptable means of testing the EPU for reliability is as follows:

7.5.1.1 The EPU shall be installed in an LSA class aircraft and while being operated in a "Flight School" manner have a documented reliability of no total power failure for a minimum of 100 flight hours. The aircraft shall be flown and stored in humidity, temperature and altitude conditions for which the manufacturer states the electric propulsion unit may operate under in the operating manual required in 5.2.4. Maintenance of the EPU during the demonstration shall be as defined in the maintenance manuals and if any major component is replaced, other than those specified in the maintenance manual as limited life components requiring replacement between overhaul intervals, the 100 flight hour demonstration shall restart at 0 h. The electric propulsion system used for the demonstration shall be the same hardware and software of that being certified under this standard.

7.5.1.2 EPUs previously certified per 7.5.1.1 of this document of which have had minor hardware changes or have had software revisions shall demonstrate the system reliability by repeating the flight demonstration as outlined in 7.5.1.1 for 50 flight hours.

7.5.2 Creation of a documented test procedure and development plan that meets the intent of the required reliability outlined in 7.5 and 7.5.1.

NOTE 2—As a minimum, the electric propulsion system should have a demonstrated reliability as that for existing spark ignition internal combustion engines used in the LSA aircraft.

8. Manufacturing Requirements

8.1 The EPU manufacturer shall establish inspections and tests necessary to ensure that each article produced conforms to the design and is in a condition for safe operation. The manufacturer shall have in place a Quality Assurance system that documents delivered quality and a Quality Control System. The Quality Program shall comply with Specification F2972 requirements.

8.2 A system for informing company inspectors of current changes in engineering drawings, specifications, firmware and software, and quality control procedures.

9. Keywords

9.1 electric propulsion unit (EPU); energy storage devices (ESD); light sport aircraft (LSA)

APPENDIXES

(Nonmandatory Information)

X1. ELECTRIC PROPULSION TECHNOLOGY CONCEPTS

X1.1 *Electric Aircraft (EA)*—An aircraft that uses one or more electric motors for propulsion. Depending on the type of aircraft, motion may be by propellers, driven by a ducted fan, or any other means of converting electricity to propulsion.

X1.2 *Electric Propulsion Unit (EPU)*—Any electric motor and all associated devices used to provide thrust for an electric aircraft.

X1.3 *Energy Storage Device (ESD)*—Any manner that stores some form of energy that can be drawn upon at a later time to perform some useful operation. Typical energy storage devices include but are not limited to: batteries, fuel cells or capacitors.

X1.4 *In-flight Electrical Emergency (IEE)*—Any emergency caused by a malfunction or damage to the EPU or ESD.

X1.5 *Brushless DC Motor*—A synchronous electric motor which is powered by direct current electricity and which has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes. In such motors, current and torque, voltage and rpm are linearly related.

X1.6 *Brushed DC Motor*—An internally commutated electric motor designed to be run from a DC power source.

X1.7 *Lithium-Polymer Batteries*—Lithium-ion polymer batteries, polymer lithium ion or more commonly lithium polymer rechargeable batteries which have technologically evolved from lithium ion batteries. Typically a lithium-salt electrolyte is held in a solid polymer composite such as polyethylene oxide or polyacrylonitrile, although different cell chemistries are possible. Lithium polymer batteries have very high energy densities.

X1.8 *Motor Controller*—A device or devices that serves to govern the performance of an electric motor. It could include a manual or automatic means for starting or stopping the motor, selecting direction of rotation, selecting and regulating motor speeds, regulating or limiting the torque and protecting against overloads and faults.

X1.9 *Battery*—A device composed of electrochemical cells used to convert chemical energy to electrical energy.

X1.10 *Capacitors*—A passive electrical device consisting of a pair of conductors separated by a dielectric (insulator). When a potential difference (voltage) exists across the conductors, an electric field is present in the dielectric. This field stores energy.

X1.11 *Isolation*—The electrical resistance between the battery high voltage system and any airframe conductive structure.

X2. ADVANCED TECHNOLOGY BATTERIES

INTRODUCTION

Several industry and governmental agencies have developed technical guidelines regarding the use of advanced technology batteries in both ground and air vehicles. In the United States, the Society of Automotive Engineers (SAE) has issued SAE J2344, covering ground vehicles. The reader is encouraged to review this document for reference. In Europe, EASA (European Aviation Safety Agency) has identified in its document EASA CRI F-58 a number of best practices deemed appropriate for the inclusion of advanced technology batteries (ATB) for use in manned electric aircraft. A synopsis of EASA CRI F-58 follows:

X2.1 *Overcharging*—Li batteries in general are significantly more susceptible to internal failures that can result in self-sustained increases in temperature and pressure (that is, thermal runaway) than their Ni-Cd and lead acid counterparts. This is especially true for over charging which causes heating and destabilization of the components of the cell which can cause the formation of highly unstable metallic lithium which can ignite resulting in a self-sustaining fire or explosion. Certain types of Li batteries pose a potential safety problem because of the instability and flammability of the organic electrolyte employed by the cell of some Li battery types. The severity of thermal runaways increases with increasing battery capacity, due to the high amount of electrolyte in larger batteries. Therefore the ground charging of lithium ATB should be approached with the same care, concern, and safety as the gasoline or jet fueling of aircraft.

X2.2 *Over Discharging*:

X2.2.1 Discharge of some versions of the Li cell beyond a certain voltage can cause corrosion of the electrodes of the cell resulting in loss of battery capacity that cannot be reversed by recharging. This loss of capacity may not be detected by the simple voltage measurements commonly available to flight crews as a means of checking battery status, a problem shared with Ni-Cd batteries.

X2.2.2 Safe cell temperatures and pressures must be maintained during any probable charging or discharging condition, or during any failure of the charging or battery monitoring system not shown to be extremely remote. The lithium battery installation must be designed to preclude explosion in the event of those failures. Lithium batteries must be designed to preclude the occurrence of self sustaining uncontrolled increases in temperature or pressure. No explosive or toxic gasses emitted by any lithium battery in normal operation or as the result of any failure of the battery charging or monitoring system, or battery installation not shown to be extremely remote, may accumulate in hazardous quantities within the airplane. No corrosive fluids or gasses that may escape from any lithium battery may damage surrounding airplane structures or adjacent essential equipment. Each lithium battery installation must have provisions to prevent any hazardous effect on the structure or essential systems that may be caused by the maximum amount of heat the battery can generate during a short circuit of the battery or of its individual cells. Lithium battery installations must have a system to control the charging rate of the battery automatically so as to prevent battery overheating or overcharging. A battery temperature sensing and over-temperature warning system with a means for automatically disconnecting the battery from its charging source in the event of an over-temperature condition should be included. A battery failure sensing system and warning system with a means for automatically disconnecting the battery from its charging source in the event of battery failure should be included in the EPU design. A lithium battery installation whose function is required for safe operation of the airplane, must incorporate a monitoring and warning feature that will provide an indication to the appropriate flight crew members, whenever the capacity and state of charge (SOC) of the batteries have fallen below levels considered acceptable for flight. The operational manual for the ESD (lithium ATB's) must contain procedures for lithium batteries in spares storage to prevent replacement of batteries whose function is required for safe flight, with batteries that have experienced degraded charge retention or other damage due to prolonged storage at low SOC.

X2.3 *Flammability of Cell Components*:

X2.3.1 Unlike Ni-Cd and lead acid cells, some types of lithium cells employ, in a liquid state, electrolytes that are known to be flammable. This material can serve as a source of fuel for an external fire in the event of a breach of the cell container. In comparison to the flammability of conventional fuels such as gasoline or jet fuel, this characteristic of lithium batteries should not be overly alarming except to say that vigilance should be maintained in the use of ATB's to guard against fire hazard complacency.

X2.3.2 It is envisaged that the core science of ATB's will continue to evolve in the future, and that the Committee's work will evolve with the science, that tailoring of requirements may be made such that more elegant and robust EPU and ESD designs can flourish. It is the intent that the work of this Committee not only establish technical order by the issuance of specifications, but also to advance the aeronautical sciences.