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Standard Specification for Design of Electric Engines for General Aviation Aircraft[1]

This standard is issued under the fixed designation F3338; 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 specification covers minimum requirements for the design of electric engines.

1.2 Distributed propulsion is not excluded; however, additional requirements will be needed to address the additional issues that distributed propulsion can create. Some of those issues may include: use of a common motor controller/inverter, segregated electric harnesses, cooling systems, electric power supplies, and others.

1.3 This specification does not address all of the requirements that may be necessary for possible hybrid configurations where an electric engine and a combustion engine drive a common thruster. This specification may be used for the electric engine aspects with supplemental requirements for the thruster and the combustion engine.

1.4 Although this specification does not include specific requirements for electric engines that include gearboxes, thrusters, or any energy storage systems, it also does not preclude such capabilities. This specification may be used for the base electric engine aspects of the design, with supplemental requirements for any additional features prepared by the manufacturer and submitted to the Civil Airworthiness Authority for acceptance. This version of this ASTM specification also does not address all of the requirements necessary for configurations of motor driven ducted-fans. It is anticipated that the fan would be subject to parts of 14 CFR 33 or CS-E and/or 14 CFR 35 or CS-P, or equivalent, in particular blade-off and bird strike. These would be conducted on the fan as a unit (including motor) rather than on motor or fan alone.

1.5 The applicant for a design approval should seek the individual guidance of their respective civil aviation authority (CAA) body concerning the use of this specification as part of a certification plan. For information on which CAA regulatory bodies have accepted this specification (in whole or in part) as a means of compliance to their general aviation aircraft airworthiness regulations (hereinafter referred to as "the Rules"), refer to ASTM Committee F39 webpage (www.ASTM.org/COMITTEE/F39.htm), which includes CAA website links.

1.6 When applicable, this specification may be used for electric engines with a fixed-pitch propeller or fan. These configurations may be type-certificated as an electric engine including a thruster. There may be additional requirements not currently included in this specification for this type configuration. In addition, 5.25 is included as a test requirement for the electric engine. That section recognizes that when the electric engine does not have an integral thruster it will need to be tested with a representative load on the drive shaft to ensure the engine's ability to operate properly with static and dynamic loads.

1.7 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.8 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standard:*
F3060 Terminology for Aircraft
2.2 *Code of Federal Regulations:*[2]
14 CFR 33 Airworthiness Standards: Aircraft Engines
14 CFR 35 Airworthiness Standards: Propellers
2.3 *EASA Standards:*[3]
CS-E Engines
CS-P Propellers

[1] This specification is under the jurisdiction of ASTM Committee F39 on Aircraft Systems and is the direct responsibility of Subcommittee F39.05 on Design, Alteration, and Certification of Electric Propulsion Systems.

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[2] Available from U.S. Government Publishing Office (GPO), 732 N. Capitol St., NW, Washington, DC 20401, http://www.gpo.gov.

[3] Available from European Aviation Safety Agency (EASA), Postfach 10 12 53, D-50452 Cologne, Germany, http://www.easa.europa.eu.

2.4 *IEC Standards:*[4]

IEC 60034-1 Rotating electrical machines – Part 1 Rating and performance

IEC 60349-4 Electric traction – Rotating electric machines for rail and road vehicles – Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter

2.5 *SAE Standard:*[5]

SAE J245 Engine-Rating Code~Spark Ignition

3. Terminology

3.1 Terminology specific to this specification is provided below. For general terminology, refer to ASTM F3060, Standard Terminology for Aircraft.

3.2 *Definitions:*

3.2.1 *duty types, n—*

3.2.1.1 *non-periodic duty, n—*in which generally load and speed vary within the permissible operating range.

3.2.1.2 *periodic duty, n—*comprising one or more loads remaining constant for the duration specified.

3.2.2 *electric engine, n—*A type of aircraft engine that converts electric power into mechanical power or thrust used for propulsion, including those components necessary for proper control and functioning.

3.2.2.1 *Discussion—*In the context of this specification, the minimum essential components of an electric engine are an electric motor and its associated motor controller(s), disconnect(s), wiring, and sensor(s). Other components and accessories necessary for proper control and function are typically considered part of the engine; for example: inverters, liquid cooling components, liquid lubrication components, thrusters, etc.

3.2.3 *energize, v—*the act of connecting the electric engine to the electrical power source such that the engine enters a ready state where throttle input results in shaft rotation. De-energize is the opposite of energize.

3.2.4 *hazardous electric engine effects, n—*the following effects are regarded as hazardous electric engine effects:

(1) Non-containment of high-energy debris;

(2) Significant brake power in the opposite direction to that commanded by the pilot;

(3) Uncontrolled fire;

(4) Failure of the engine mount system leading to inadvertent engine separation;

(5) Release of the propeller or fan or any major portion of the propeller or fan by the engine, if applicable;

(6) Complete inability to shut the engine down; and

(7) The serious or fatal injury to flight crew, passengers, or ground-handling personnel arising from electric shock.

3.2.5 *inverter, n—*a power electronic device or circuitry that changes direct current (DC) to alternating current (AC). The motor controller is often integrated with the inverter.

3.2.6 *motor, n—*a machine that converts electrical power into rotational mechanical power.

3.2.7 *motor controller, n—*a device or devices that serves to manage the operation of an electric motor.

3.2.7.1 *Discussion—*It could include a manual or automatic means for energizing, 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. The inverter is often integrated with the motor controller.

3.2.8 *rated maximum continuous power, n—*with respect to an electric engine, the approved brake power that is developed statically or in flight, in standard atmosphere at a specified altitude, within the engine operating limitations established under CAA requirements, and approved for unrestricted periods of use.

3.2.8.1 *Discussion—*Brake power is defined in SAE J245 as the power available at the flywheel or other output member(s) for doing useful work.

3.2.9 *rated takeoff power, n—*with respect to electric engine type certification, the approved brake horsepower that is developed statically under standard sea level conditions, within the engine operating limitations established under CAA requirements, and limited in use to periods of not over 5 min for takeoff operation.

3.2.10 *shaft power, n—*the brake power delivered at an engine's drive shaft.

3.2.10.1 *Discussion—*References to electrical power are called out as such.

3.2.11 *thrust, n—*The propulsive force generated by the aircraft engine that is used to move an aircraft through the air.

3.2.11.1 *Discussion—*As used in this specification, applies to endurance, durability, and systems tests.

3.2.12 *thruster, n—*as used in this specification, a device such as propeller, rotor, or fan for translating mechanical/rotational energy to thrust.

3.3 *Abbreviations:*

3.3.1 *EMI—*electromagnetic interference

3.3.2 *HIRF—*high-intensity radiated field

4. Significance and Use

4.1 This specification provides designers and manufacturers of electric propulsion for General Aviation aircraft references and criteria to use in designing and developing electric engines with the intent of gaining approval from a civil aviation authority.

4.2 Appendix X1 provides additional (but not necessarily all) information and guidance to meet certification or airworthiness requirements, or both, for a particular country or area under the jurisdiction of a civil aviation authority.

5. Requirements in Support of Certification or Approval

5.1 *Instructions for Continued Airworthiness:*

5.1.1 Instructions for the continued airworthiness of the electric engine must be prepared. The instructions may be incomplete at the time of certification or approval:

[4] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, 1st Floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

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

5.1.1.1 If a program exists to ensure their completion prior to delivery of the first aircraft with the engine installed, or

5.1.1.2 Upon CAA approval for the aircraft with the engine installed, whichever occurs later.

5.1.2 A maintenance manual shall be provided that defines maintenance requirements for the continued airworthiness of the engine, such as periodic installed maintenance, major inspections, repairs, 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 engine also includes special equipment or testing required to ensure the electrical propulsion system is safe to continued operation.

5.1.3 If applicable, an overhaul manual that provides instructions for disassembling, replacing, or overhauling components identified in the manual for such, in order to return the engine to airworthy condition that is safe for operation until the next major overhaul.

5.1.4 Updates to the Instructions for Continued Airworthiness must be made available by the engine manufacturer or other responsible party such that those instructions remain current.

5.2 *Instruction Manual for Installing and Operating the Electric Engine:*

5.2.1 Instructions for installing and operating the engine must be made available to the CAA as part of the certification process and to the customer at the time of delivery. The instructions must include directly, or by reference to appropriate documentation, at least the following:

5.2.1.1 *Installation Instructions*—Coordination is recommended between the engine manufacturer and the installer. However, if the installer is not identified at the time of the engine design, the following aspects still need definition in the installation instructions.

(1) An outline drawing of the engine including overall dimensions.

(2) A definition of the physical and functional interfaces of all elements of the engine, with the aircraft and aircraft equipment, including the propeller or fan, when applicable. Including the location and description of the engine connections for attachment of accessories, wires, cables, cooling ducts, cowling, and any other equipment attached to the engine.

(3) Where an electric engine relies on components that are not part of the engine type design, the interface conditions and reliability requirements for those components, as used in the safety analysis, must be specified in the engine installation instructions. If reliability values used in the safety analysis are based on assumptions, these assumed values must be specified in the engine installation instructions. Requirements for mitigation means, that are not part of the engine, must be specified in the engine installation instructions and the engine operating instructions.

(4) A list of the instruments necessary for the control and operation of the electric engine, including the overall limits of accuracy and transient response requirements, must be stated in a manner that allows the satisfactory nature of instruments as installed to be determined.

NOTE 1—"Instrument" is used to refer to any device necessary to measure engine parameters and convey them to the appropriate decision-making center, be that a pilot or software-based control.

(5) The limits on environmental conditions, including EMI, HIRF, and lightning for which the engine was designed and qualified.

5.2.1.2 *Operating Instructions:*

(1) The operating limitations established within the showing of compliance.

(2) The power ratings and procedures for correcting for nonstandard atmosphere.

(3) The recommended procedures, under normal and critical ambient conditions for:

(a) Powering on;

(b) Operating on the ground;

(c) Operating during flight.

(4) A description of the primary and all alternate modes, and any back-up system, together with any associated limitations, of the engine control system and its interface with the aircraft systems, including the propeller or fan if these are integral with the engine.

5.3 *Electric Engine Operating Limitations and Ratings:*

5.3.1 Ratings and operating limitations are established by the administrator and included in the product certificate data sheet, including ratings and limitations based on the operating conditions and information specified in this section, as applicable, and any other information found necessary for safe operation of the engine.

5.3.2 Electric engine operating limitations are established as applicable, including:

5.3.2.1 Maximum transient overspeed and time;

5.3.2.2 Maximum transient overtorque and time, and number of overtorque occurrences;

5.3.2.3 Maximum overtorque and time;

5.3.2.4 Electrical power, voltage, current, frequency, and electrical power quality limits;

5.3.2.5 Maximum rated temperature(s);

5.3.2.6 Maximum and minimum continuous temperature, current, voltage;

5.3.2.7 Vibration limits; and

5.3.2.8 Any other information necessary for safe operation of the engine.

5.3.3 Electric engine ratings are established, as applicable, and are based on the intended duty cycle and the assignment of ratings as defined below, including:

5.3.3.1 Power, torque, speed, and time for:

(1) Rated maximum continuous power, and

(2) Rated maximum temporary power and associated time limit.

5.3.4 *Duty Cycle:*

5.3.4.1 *Declaration of Duty*—The intended duty cycle of the motor of the electric engine sets the framework for establishment of the ratings. There are a number of typical duty cycles used for electric motors. (See IEC 60034-1.) As the duty cycle combined with the rating at that duty cycle establishes the capability and the limits for the engine's use, the manufacturer declares the duty cycle or cycles. These can be based on the manufacturer's intended use for the engine or may be based on the required duty cycle of the installer. As detailed in IEC 60034-1, multiple duties and their associated ratings may be established to address various operational conditions. The duty may be described by one of the following:

(1) Numerically, where the load does not vary or where it varies in a known manner; or

(2) As a time sequence graph of the variable quantities; or

(3) By selecting one of the typical duty types in accordance with IEC 60034-1, Paragraph 4 Duty, that is no less onerous than the expected duty.

5.3.5 *Assignment of Rating*—The rating, as defined by "set of rated values and operating conditions," shall be assigned by the manufacturer. In assigning the rating, the manufacturer shall select one of the classes of rating as defined in the IEC 60034-1 Paragraph 5 Ratings.

5.3.6 *Motor Rate Output*—The rated output is the mechanical power available at the shaft and shall be expressed in watts (W).

NOTE 2—It is the practice in some countries for the mechanical power available at the shafts of motors to be expressed in horsepower (1 hp is equivalent to 745,7 W; 1 ch (cheval or metric horsepower) is equivalent to 736 W).

5.3.7 *Machines with More Than One Rating*—For machines with more than one rating, the machine shall comply with this specification in all respects at each rating. For multi-speed machines, a rating shall be assigned for each speed. When a rated quantity (output, voltage, speed, etc.) may assume several values or vary continuously within two limits, the rating shall be stated at these values or limits.

5.3.8 Each selected rating must be for the lowest power that all electric engines of the same type may be expected to produce under the conditions used to determine that rating at all times between overhaul periods or other maintenance.

5.4 *Materials:*

5.4.1 The materials and components used in the engine must be established on the basis of industry or military specification(s) for the intended design conditions of the system. The assumed design values of properties of materials must be suitably related to the minimum properties stated in the material specification. Otherwise, proof of suitability and durability acceptable to the CAA must be established on the basis of tests or other means that ensure their having the strength and other properties assumed in the design data.

5.4.2 Manufacturing methods and processes must be such as to produce sound structure and mechanisms, and electrical systems that retain the design properties under reasonable service conditions. This includes the effects of corrosion.

5.5 *Fire Protection:*

5.5.1 The design and construction of the engine and the materials used must minimize the probability of the occurrence and spread of fire during normal operation and engine failure conditions and must minimize the effect of such a fire. The engine high voltage electrical wiring interconnect systems should be protected against arc-faults. Any nonprotected electrical wiring interconnects should be analyzed to show that arc faults do not cause a hazardous condition. If flammable fluids are used, then this must be stated in any required installation instructions so that consideration may be given (at the aircraft level) to determining if a fire zone must be established under the associated aircraft certification rules.

5.6 *Durability:*

5.6.1 Electric engine design and construction must minimize the development of an unsafe condition of the engine between maintenance intervals, removal from service or overhaul periods or mandated life defined in the Instructions for Continued Airworthiness, as applicable.

5.7 *Electric Engine Cooling:*

5.7.1 Engine cooling shall be sufficient under all conditions within the declared operational limitations to prevent component temperatures exceeding applicable limits..

5.7.2 If aspects of the cooling require the installer to ensure that the temperature limits are met, those limits shall be specified in the installation manual.

5.7.3 Instrumentation or sensors shall be provided to enable the flight crew or the automatic control system to monitor the functioning of the engine cooling system unless appropriate inspections are published in the relevant manuals and evidence shows that:

5.7.3.1 Failure of the cooling system would not lead to hazardous electric engine effects defined in 3.2.4 before detection; or

5.7.3.2 Other existing instrumentation or sensors provides adequate warning of failure or impending failure; or

5.7.3.3 The probability of failure of the cooling system is extremely remote.

5.7.4 An electric engine with a liquid cooling system shall also meet the applicable requirements of 5.18.

5.8 *Electric Engine Mounting Attachments and Structure:*

5.8.1 The maximum allowable limit and ultimate load for the integral engine mounting attachment points and related engine structure must be specified.

5.8.2 The engine mounting attachments and related engine structure must be able to withstand:

5.8.2.1 The specified limit loads without permanent deformation; and

5.8.2.2 The specified ultimate loads without failure but allowing for permanent deformation.

5.8.3 If flammable fluids are used within the electric engine, the mounts and the mounting features must be demonstrated to be fireproof.

5.9 *Electric Engine Rotor Overspeed:*

5.9.1 The rotors must, including any integral fan rotors used for cooling:

5.9.1.1 Possess sufficient strength with a margin to burst above certified operating conditions and above failure conditions leading to rotor overspeed, and

5.9.1.2 Do not exhibit a level of growth or damage that could lead to a hazardous electric engine effect.

5.9.2 *Burst*—For each rotor of the electric engine, it must be established by test, analysis, or a combination of both, that each rotor will not burst when subjected to the analysis and test conditions in accordance with IEC 60349, Part 4, or an equivalent standard.

5.9.2.1 Unless otherwise specified in IEC 60349, Part 4, test rotors used to demonstrate compliance with this section that do not have the most adverse combination of material properties and dimensional tolerances must be tested at conditions which have been adjusted to ensure the minimum specification rotor possesses the required overspeed capability. This can be accomplished by increasing test speed, temperature, or loads, or combinations thereof.

5.9.2.2 When an electric engine test is being used to demonstrate compliance with the overspeed conditions listed in 5.9.3 of this section and the failure of a component or system is sudden and transient, it may not be possible to operate the electric engine for 5 min after the failure. Under these circumstances, the actual overspeed duration is acceptable if the required maximum overspeed is achieved as required by IEC 60349-4.

5.9.3 *Max Overspeed*—When determining the maximum overspeed condition applicable to each rotor in order to comply with 5.9.2 of this section, the evaluation must include the test conditions as specified in IEC 60034-1 and the following:

5.9.3.1 One hundred twenty percent of the maximum permissible rotor speed associated with any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.

5.9.3.2 One hundred fifteen percent of the maximum no-load speed associated with any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.

5.9.3.3 One hundred five percent of the highest rotor speed that would result from either:

(1) The failure of the component or system which, in a representative installation of the engine, is the most critical with respect to overspeed when operating at any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.

(2) The failure of any component or system in a representative installation of the engine, in combination with any other failure of a component or system that would not normally be detected during a routine pre-flight check or during normal flight operation, that is the most critical with respect to overspeed, except as provided by 5.9.4 of this section, when operating at any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.

5.9.4 *Loss of Load*—The highest overspeed that results from a complete loss of load on an engine rotor, must be determined and included in the overspeed conditions considered by 5.9.3 of this section. The complete loss of load must also consider:

5.9.4.1 Demagnetization in combination with excessive external torque imposed (propeller induced no-load overspeed),

5.9.4.2 Failures external to the e-motor, and

5.9.4.3 Combinations of failures unless those combinations can be shown to be extremely remote.

5.9.5 *Growth*—In addition, each engine rotor must comply with 5.9.5.1 and 5.9.5.2 of this section for the maximum overspeed achieved when subjected to the conditions specified in 5.9.3 of this section. It must be established using the approach in 5.9.2 of this section that specifies the required test conditions.

5.9.5.1 Rotor growth must not cause the motor operation to lead to a hazardous electric engine effect.

5.9.5.2 Following an overspeed event and after continued operation, the rotor may not exhibit conditions such as cracking or distortion, which preclude continued safe operation.

5.9.6 *Controls*—The design and functioning of engine control systems, instruments, and other methods not covered under 5.10 must ensure that the engine operating limitations that affect rotor structural integrity will not be exceeded in service.

5.9.7 *Shaft Failure*—Failure of a shaft section may be excluded from consideration in determining the highest overspeed that would result from a complete loss of load on a rotor if it can be shown that:

5.9.7.1 The shaft is identified as an engine life-limited-part and complies with 5.15.

5.9.7.2 The engine uses material and design features that are well understood and that can be analyzed by well-established and validated stress analysis techniques.

5.9.7.3 It has been determined, based on an assessment of the environment surrounding the shaft section, that environmental influences are unlikely to cause a shaft failure. This assessment must include complexity of design, corrosion, wear, vibration, fire, contact with adjacent components or structure, overheating, and secondary effects from other failures or combination of failures.

5.9.7.4 It has been identified and declared, in accordance with 5.2, any assumptions regarding the engine installation in making the assessment described above in 5.9.7.3 of this section.

5.9.7.5 It has been assessed, and considered as appropriate, experience with shaft sections of similar design.

5.9.7.6 The entire shaft has not been excluded.

5.9.7.7 Rationale is provided that the e-motor electrodynamic principle yields intrinsic safety against uncontrollable overspeed in case of rotor shaft failure.

5.9.8 *Use of Analysis*—If analysis is used to meet the overspeed requirements, then the analytical tool must be validated to prior overspeed test results of a similar rotor. The tool must be validated for each material. The rotor being certified must not exceed the boundaries of the rotors being used to validate the analytical tool in terms of geometric shape, operating stress, and temperature. Validation includes the ability to accurately predict rotor dimensional growth and the burst speed. The predictions must also show that the rotor being certified does not have lower burst and growth margins than rotors used to validate the tool.

5.10 *Electric Engine Controls:*

5.10.1 The software and complex electronic hardware, including programmable logic devices, shall be designed and developed using a structured and methodical approach that provides a level of assurance for the logic, that is commensurate with the hazard associated with the failure or malfunction of the systems in which the devices are located, and is substantiated by a verification methodology acceptable to the CAA.

5.10.2 *Applicability*—These requirements are applicable to any system or device that controls, limits, monitors, or protects the engine operation, and is necessary for the continued airworthiness of the engine. If items that influence the engine system are outside of the engine manufacturer's control, the assumptions with respect to the reliability and functionality of these parts must be clearly stated in the safety analysis (see 5.19).

5.10.3 *Validation:*

5.10.3.1 *Functional Aspects*—It must be substantiated by tests, analysis, or a combination thereof, that the engine control system performs the intended functions in a manner which:

(1) Enables selected values of relevant control parameters to be maintained and the engine kept within the approved operating limits over changing atmospheric conditions in the declared flight envelope;

(2) Complies with the operability requirements of operation and power response tests, as appropriate, under all likely system inputs and allowable engine power demands, unless it can be demonstrated that failure of the control function results in a nondispatchable condition in the intended application;

(3) Allows modulation of the engine output power with adequate sensitivity over the declared range of engine operating conditions; and

(4) Does not create unacceptable power oscillations.

5.10.3.2 *Environmental Limits*—Environmental limits that cannot be adequately substantiated in accordance with endurance testing must be demonstrated, by means of electric engine system and component tests (see 5.13). These tests demonstrate that the engine control system functionality will not be adversely affected by declared environmental conditions, including electromagnetic interference (EMI), High Intensity Radiated Fields (HIRF), and lightning, when applicable, for the intended use. The limits to which the system has been qualified must be documented in the engine installation instructions.

5.10.4 *Control Transitions*—It must be demonstrated that during both normal operation or as a result of fault or failure, changes in one control mode to another, from one channel to another, or from a primary system to a back-up system, the change occurs so that:

5.10.4.1 The engine does not exceed any of its operating limitations;

5.10.4.2 The engine does not experience any unacceptable operating characteristics or transient exceedances of any limit potentially leading to unsafe operating conditions. Such non-acceptable operating characteristics include but are not limited to:

(1) Field excitation at rotor resonance frequency,

(2) Electromagnetic lock-up (stall),

(3) Unacceptable power changes or oscillations, and

(4) Other unacceptable characteristics, for example, electrical arcs, overspeed, or overtorque.

5.10.4.3 There is a means to signal the aircraft to take action or monitor the control transition. The means to alert the aircraft must be described in the installation instructions, and the action or monitoring required must be described in the engine operating instructions.

5.10.4.4 The magnitude of any change in power and the associated transition time must be identified and described in the engine installation instructions and the engine operating instructions.

5.10.5 *Electric Engine Control System Failures*—The engine control system must:

5.10.5.1 Have a maximum rate of Loss of Power Control (LOPC) events that is consistent with the intended application;

5.10.5.2 Be, in the full-up configuration (that is, with no currently active faults), essentially single fault tolerant, as determined by the CAA, for electrical, electrically detectable, and electronic failures with respect to LOPC events;

5.10.5.3 Not have single failures that result in hazardous electric engine effect(s); and

5.10.5.4 Not have likely failures or malfunctions that lead to local events in the intended aircraft installation, such as arcing, fire, overheat, or other failures that result in a hazardous electric engine effect due to an engine control system's failure or malfunction.

5.10.6 *System Safety Assessment*—This assessment must identify faults or failures that affect normal operation together with the predicted frequency of occurrence of these faults or failures.

5.10.7 *Protection Systems:*

5.10.7.1 The design and functioning of the engine control devices and systems, together with the engine instruments and operating and maintenance instructions, must provide reasonable assurance that those engine operating limitations that affect the structural integrity of the rotating parts, or the electrical integrity of the engine electrical system will not be exceeded in service.

5.10.7.2 When electronic overspeed protection systems are provided, the design must include a means for testing, at least once per engine start/stop cycle, to establish the availability of the protection function. The means must be such that a complete test of the system can be achieved in the minimum number of cycles. If the test is not fully automatic, the requirement for a manual test must be contained in the engine operating instructions.

5.10.7.3 When overspeed protection is provided through hydromechanical or mechanical means, it must be demonstrated by test or other acceptable means that the overspeed function remains available between inspection and maintenance periods.

5.10.8 *Aircraft-supplied Data*—Single failures leading to loss, interruption or corruption of aircraft-supplied data (other than power command signals from the aircraft), or data shared between independent electrodynamic systems within a single engine or fully independent engine systems must:

5.10.8.1 Not result in a hazardous electric engine effect for any electric engine; and

5.10.8.2 Be detected and accommodated. The accommodation strategy must not result in an unacceptable change in power or an unacceptable change in engine operating characteristics. The effects of these failures on engine power and on engine operating characteristics throughout the declared operating envelope and operational environment must be evaluated and documented in the engine installation instructions.

5.10.9 *Electric Engine Control System Electrical Power:*

NOTE 3—The historic basis for this section was to address the use of aircraft supplied electrical power to the engine control system in addition to the use of a dedicated electrical power source, very typically an engine driven permanent magnet alternator (PMA). The aircraft supplied electrical power was most often used as a backup to the PMA electrical power.

5.10.9.1 The engine control system must be designed such that the loss, malfunction, or interruption of the engine control system electrical power source will not result in any of the following:

(1) A hazardous electric engine effect, or

(2) The unacceptable transmission of erroneous data, or

(3) The continued operation, running of the engine in the absence of the control function.

5.10.9.2 The primary electrical power source for the engine control system must have sufficient capacity to ensure its operation at least as long as the electric engine when using all possible engine electrical power sources.

5.10.9.3 If any electrical power is supplied from the aircraft to the engine control system for powering on and operating the engine, the need for and the characteristics of this electrical power, including transient and steady state voltage limits, must be identified and declared in the engine installation instructions.

5.10.10 *Electric Engine Shut Down Means*—Means must be provided for shutting down the engine rapidly.

5.11 *Instrument or Sensor Connection:*

5.11.1 Provisions must be made for the installation of instrumentation or sensors necessary to ensure engine operation within all operating limitations.

5.11.2 The instrument or sensor connections must be designed or labeled to ensure a correct connection.

5.11.3 Any instrumentation on which the Safety Analysis (see 5.19) depends must be specified and declared mandatory in the engine installation instructions and approval documentation.

5.11.4 The sensors, together with their data transmission hardware and signal conditioning, must be segregated electrically and physically to the extent necessary, to ensure that the probability of a fault propagating from instrumentation and monitoring functions to control functions, or vice versa, is consistent with the failure effect of the fault.

5.12 *Vibration*—The engine must be designed and constructed to function throughout its normal operating range of rotor speeds and engine output power without inducing excessive stress in any of the engine parts because of vibration and without imparting excessive vibration forces to the aircraft structure. In addition to historical sources of vibration such as aerodynamic excitation, analysis of rotating component resonance induced by field-excitation, should also be assessed,

5.13 *Electric Engine System and Component Tests:*

5.13.1 For those systems and components that cannot be adequately substantiated in accordance with endurance testing, additional tests must be conducted to demonstrate that systems or components are able to perform the intended functions in all declared environmental and operating conditions.

5.13.2 Temperature limits must be established for each component that requires temperature-controlling provisions in the aircraft installation to assure satisfactory functioning, reliability, and durability.

5.13.3 Voltage and current limits must be established for each component that requires voltage or current controlling provisions, or both, in the aircraft installation to assure satisfactory functioning, reliability, and durability.

5.14 *Stress Analysis:*

5.14.1 A mechanical stress analysis, to show complete understanding of the operating conditions that limit the design, must be performed on each engine showing the design safety margin of each rotor, stator, and housing of the electric engine.

5.14.2 An electrical stress analysis must be performed on each engine showing the electrical design safety margin of each electrical component above 220 VAC or 48 VDC.

5.14.3 Testing would be a suitable means of compliance with the "stress analysis" requirement, if it can be shown that all of the limiting conditions have been tested.

5.15 *Electric Engine Life Limited Parts and Critical Parts:*

5.15.1 The manufacturer should determine whether the rotating/moving components, bearing, shafts, nonredundant mount components should be critical parts or life-limited parts, as defined below:

5.15.1.1 A "critical part" is a part whose primary failure could cause a hazardous effect, but whose failure mechanisms are limited to high cycle fatigue or overload such that the part is not required to be removed by a certain number of flight cycles, engine operating hours, etc.

5.15.1.2 A "life-limited part" is a critical part whose failure mechanisms include low-cycle fatigue, creep, or other mechanisms such that the part must be removed after accumulating a certain number of flight cycles, operating hours, etc. to ensure an acceptable level of safety. Electric engine life-limited parts may include, but are not limited to, rotating/moving components, bearings, shafts, nonredundant mount components, high-voltage electrical components or the entire engine.

5.15.2 *Requirements for Critical Parts*—The integrity of each critical part identified by the safety analysis must be established by:

5.15.2.1 A defined engineering process for ensuring the integrity of the critical part throughout its service life,

5.15.2.2 A defined manufacturing process that identifies the requirements to consistently produce the critical part as required by the engineering process, and

5.15.2.3 A defined service management process that identifies the continued airworthiness requirements of the critical part as required by the engineering process.

5.15.3 *Requirements for Life-limited Parts*—Operating limitations must be established by an approved procedure that specifies the maximum allowable number of flight cycles for