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Certification Rules and Standards Review

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EXECUTIVE SUMMARY

The report characterizes the certification practices for electric propulsion systems by modeling changes to current engine and propeller certification practices (14 CFR 23, 33 and 35 and means of compliance in standards developed by ASTM Committees F39 and F44). Industry technology paths are varied, so this report focuses on insights from the NASA X-57, Maxwell, Distributed Electric Propulsion flight demonstrator system technology project. There are 122 sections of the regulation reviewed, where 28 needed tailoring or revision.

This report reviews existing certification rules and means of compliance applicable to 14 CFR Parts 23, 33 and 35, and identifies areas where these existing rules and standards do not sufficiently capture emerging technologies in electric propulsion, integrated aero-propulsive and aero- control concepts, and simplified aircraft control schemes.

A subsequent report, Certification Rules and Standards Review Report, will use the results of this report and integrate it with NASA-supplied data from the NASA X-57 “Maxwell” Distributed Electric Propulsion flight demonstrator as an example new aircraft technology. This subsequent report will identify which requirements and standards are relevant, and areas were requirements and-or standards do not exist, may not be appropriate, or are otherwise in work, and identifies regulations and standards that appear to be either technology inhibitors or technology enablers.

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FIGURES AND TABLES

1. Abstract

The report characterizes the certification practices for electric propulsion systems by modeling changes to current engine and propeller certification practices (14 CFR 23, 33 and 35 and means of compliance in standards developed by ASTM Committees F39 and F44). Industry technology paths are varied, so this report focuses on insights from the NASA X-57, Maxwell, Distributed Electric Propulsion flight demonstrator system technology project. There are 122 sections of the regulation reviewed, where 28 needed tailoring or revision. A second report will examine the regulations to the X-57 system development products. A final report will describe a general regulatory gaps method for new vehicle concepts.

2. Introduction

A balance must be struck between: [1] current engine system certification practices are based on structural and thermodynamic considerations of internal combustion motors. [2] technology development has focused on vehicle certification questions, and historically ignored or disregarded engine propulsion system questions. The dichotomy of these two issues requires a fundamental approach to find a resolution.

Much work has been conducted in electrification of propulsion systems for transportation, especially in the automotive area, and recently in aircraft systems, and in each have arisen a variety of technology approaches. Currently each electric aircraft system has had to proceed on its individual certification path, as the regulatory environment does not yet have the means by which to monitor the electric propulsion technology space.

Accordingly, a means to understand the technology is to produce a number of swim lanes to illustrate the pathway from energy storage to propulsion.

Energy storage is the capture of energy produced at one time for use at a later time. These can be in the form of conventional aviation gasoline or Jet fuel (used in series or parallel hybrids); Batteries (pure electric, series or parallel hybrids); Other simple hydrocarbons (hydrogen fuel cells with on-board reformers); Compressed hydrogen (for hydrogen fuel cells); Liquified hydrogen (for hydrogen fuel cells); and Hydride storage of hydrogen (for hydrogen fuel cells).

Energy conversion is the process of changing energy from one of its forms into another. For an aviation application energy conversion can be electrochemical battery (self-contained reactants); Electrochemical battery (externally-supplied reactants); Hydrogen fuel cell (externally-supplied reactants); Spark ignition (SI) or compression ignition (CI) reciprocating engine running a generator (series hybrid); SI or CI reciprocating engine running a generator and a gearbox (parallel hybrid); Gas turbine engine running a generator (series hybrid); and Gas turbine engine running a generator and a gearbox (parallel hybrid).

Conversion of electrical power to means suitable to run an electric motor (typically poly-phase alternating current). If direct current, an inverter is required (with battery as electron source, Hydrogen fuel cell as electron source, and Rectifier as electron source). If alternating current, the motor may be driven directly with SI, CI or gas turbine running an alternator.

Conversion of poly-phase electrical power to mechanical power with a brushless direct current motor (Radial gap and Axial gap); Brushed DC motor; Standard poly-phase alternating current induction motor with squirrel cage rotor; and Switched reluctance.

And finally, converting mechanical power to propulsion where a low-speed, high-torque motor runs propeller; or a high-speed, low-torque motor drives a gearbox, which drives a propeller; and a high-speed motor runs a ducted fan.

Each of these domains have their unique technology issues, and, accordingly, each has unique certification and regulatory questions to be addressed.

3. Background

The process of successful aerospace technology insertion is a complex relationship between technologists and industry. Technologists, such as NASA (and formerly NACA) would have concepts and work with industry to mature the technology concepts. In the DoD (and predominantly, but not exclusively with USAF) a technology transfer process, where a military use finds benefit in a civilian context, takes place. The industry then develops a product for an intended customer, in whom there is an expectation of confidence in the product, and from whom the industry works to develop standards (through ASTM, SAE, AIAA, IEEE, RTCA and ASME, for example), certification processes through the FAA, and some forms of independent V&V and assurance through laboratory tests. This process is illustrated in Figure 1.

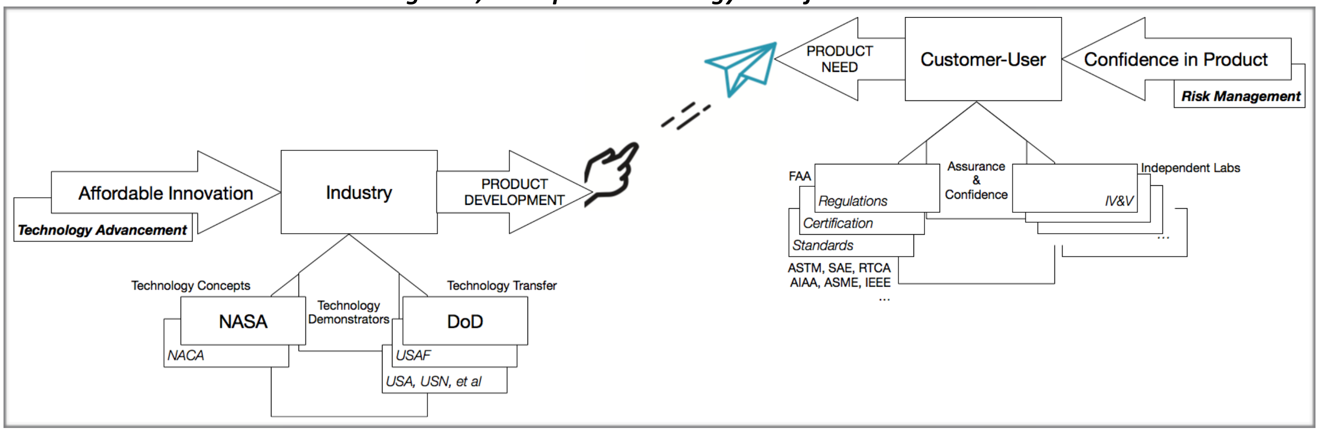
While aerospace technology insertion and development appears to be straightforward[1], the role that regulation and certification plays in the context of technology insertion is less clear. However, there are numerous examples of FAA explaining its role. For example, in March 2017, the FAA and the Association for Unmanned Vehicle Systems International (AUVSI) co-hosted the 2nd Annual FAA Unmanned Aircraft Systems (UAS) Symposium. During Workshop 10, Wes Ryan, FAA Manager, Programs and Procedures (Advanced Technology), presented “Type and Airworthiness Certifications”[2], wherein Ryan defined what certification means as an acknowledgement that FAA requirements met for aircraft, aeronautical products, airmen, mechanics, controllers, operators, etc., and that well-proven, risk-based processes for each, that they are not all the same thing and do not always apply and that each process serves a purpose to manage risk. Further, Ryan explained why FAA certification exists under Title 49 U.S. Code § 40103(a)(1), to safely manage the airspace and civil aircraft operations. The FAA certification provides

[1] Consider Joint Strike Fighter and Advanced General Aviation Transport Experiment, for example, in the 1990s.

[2] Ryan, W. (2017). *Workshop 10 – Type and Airworthiness Certifications*. Proceedings from 2nd Annual FAA Unmanned Aircraft Systems (UAS) Symposium, Reston, VA.

safety assurance that a proposed product or action will meet FAA safety expectations to protect the public.

Figure 1, Aerospace Technology Transfer



Accordingly, opportunities can be made to exist within a category of vehicles, such as general aviation, to embrace the potential for new technology insertion into certification and regulation. The *Small Airplane Revitalization Act of 2013*[3] has provided a mechanism whereby the FAA works with industry and other stakeholders through ASTM to develop consensus standards for use as a means of compliance (MOC) in certificating small airplanes under part 23.

In addition to the Small Airplane Revitalization Act, the FAA also has the ability to participate in the development of consensus standards and use consensus standards as a means of carrying out its policy objectives under the provisions of the *National Technology Transfer and Advancement Act of 1995*[4] and Office of Management and Budget (OMB) Circular A-119, "Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities," effective January 27, 2016. This approach provides the means by which new technology and vehicle concepts can be introduced into regulatory and certification processes. There is a Federal Register Notice[5] that the FAA published in May 2018 that describes accepted means of compliance for 64 such means developed by the ASTM, under F44 Committee.

The interest regarding insertion of new technologies for Normal Category Aircraft has surged in recent years. New technologies related to airborne electric propulsion and simplified or autonomous operation have introduced the potential for new, highly-integrated aircraft concepts in markets that are both

[3] Ref Pub. L. 113-53.

[4] Ref Pub. L. 104-113 as amended by Pub. L. 107-107.

[5] See https://www.federalregister.gov/documents/2018/05/11/2018-09990/accepted-means-of-compliance-airworthiness-standards-normal-category-airplanes

traditional and non-traditional for aviation. The community is eager to adopt new standards; however, little public data is available to drive development of consensus standards in these new areas. Though some manufacturers are still able to develop proprietary means of compliance for their new technologies, the regulators themselves are new to these technology areas, and need access for data from researchers to help them understand how these new technologies operate, what systems they effect, and how they may fail or otherwise function in unintended ways. The recent change to 14 CFR Part 23 to allow for consensus standards as a means of compliance, along with current, active research and flight programs related to airborne electric propulsion, integrated airframe/propulsion concepts, and simplified or autonomous aircraft control , represents a historic opportunity for NASA to help lead the aviation community – both in the development of data that can be used by consensus organizations to generate standards, as well as exchange of this data directly to the regulators to help them understand the new technologies they plan to certify.

4. Technical Approach

The foundation for a competent electric propulsion certification framework requires the ability for technical communities to communicate with each other. And so, an approach is to develop a Rosetta Stone or *lingua franca* that the communities can use. To begin the process, a set of criteria is developed based on the underlying physics of engine design, and upon which engine standards and certification are done, for internal combustion engines. The certification authorities (FAA, EASA, et al) have a very firm knowledge of this foundation and are experts in its interpretation. The next step is to cross track the underlying physics and engineering to electric propulsion units.

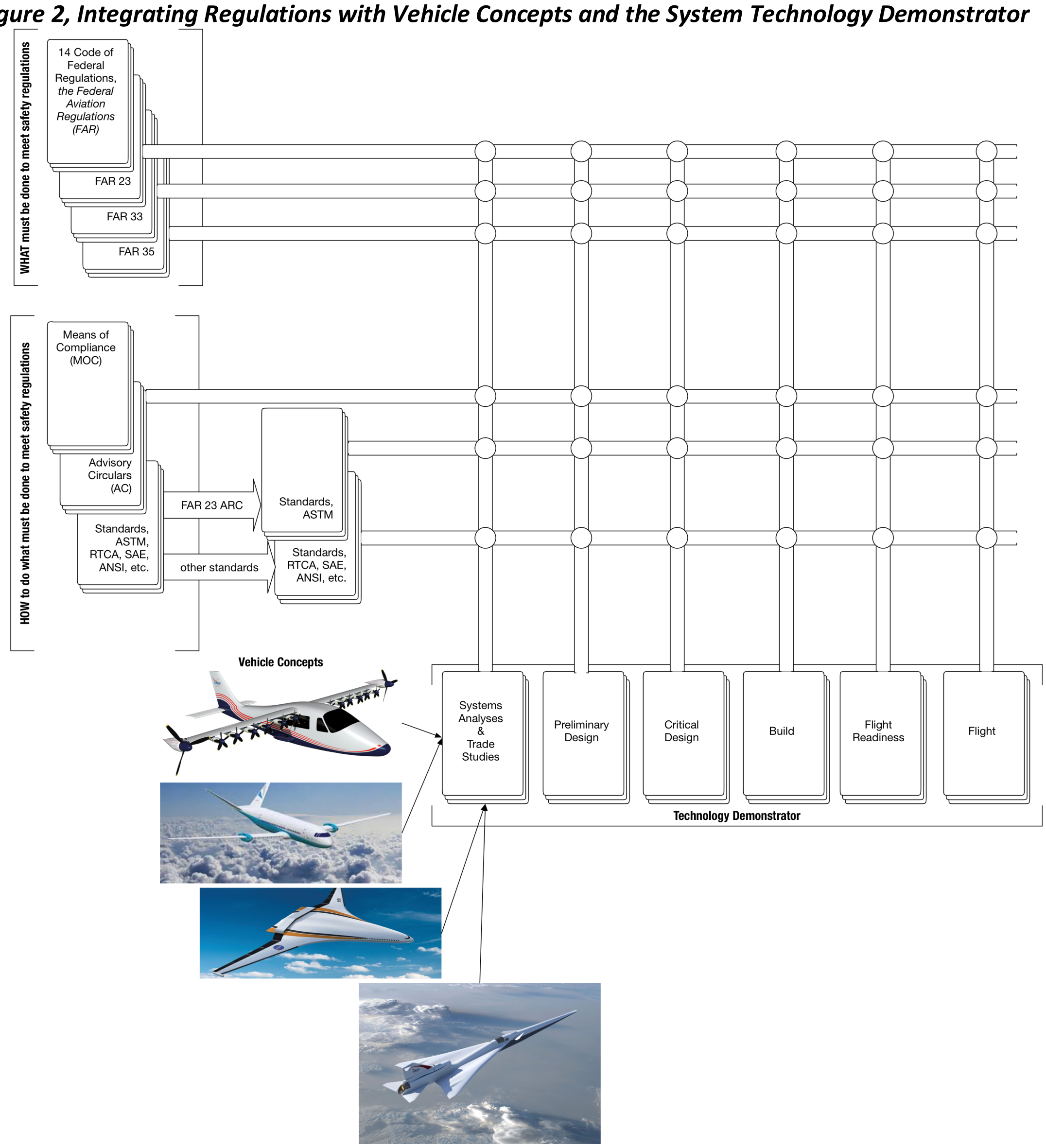
This cross tracking will provide a means by which the electric propulsion community can assess the merits of current certification practices, as well as show where other certification practices are not applicable. More importantly, this also provides the opportunity to show where new certification practices may be required, based on the physics and engineering unique to electric propulsion. This is illustrated in Figure 2, that integrates the regulatory documents with concept vehicles as they proceed through the system technology demonstrator process.

Of note, are the intersections between regulations and means of compliances, with different phases of system technology demonstrations. None of these intersections are similar. For example, the entire systems analyses and trade studies column has very little analytical relationship, currently, with either the regulations or the associated means of compliance. There is a very rich opportunity to establish such relationships. Accordingly, the "heuristic approach" is used to assess such trades based on expert knowledge of the regulations and the technology. At best this may yield soft assessments. At worst, it fosters confusion.

As one proceeds into the PDR, CDR and FRR processes, there is great opportunity to both inform the regulations (and means of compliance) by the results of the design and flight review documents. In many cases, the means of compliance is appropriate and should be used as the means of demonstrating the safety of the technology. There are a number of cases, where the results of the design and flight reviews will inform the regulations. These informers may be tailored adjustments to the regulations and means of compliance, or they might be complete revisions to regulations.

The data from the design and flight reviews becomes an essential element of the basis process for the regulator, and the responsibility of the technology demonstrator to provide sufficient technical data for its substantiation.

Figure 2, Integrating Regulations with Vehicle Concepts and the System Technology Demonstrator

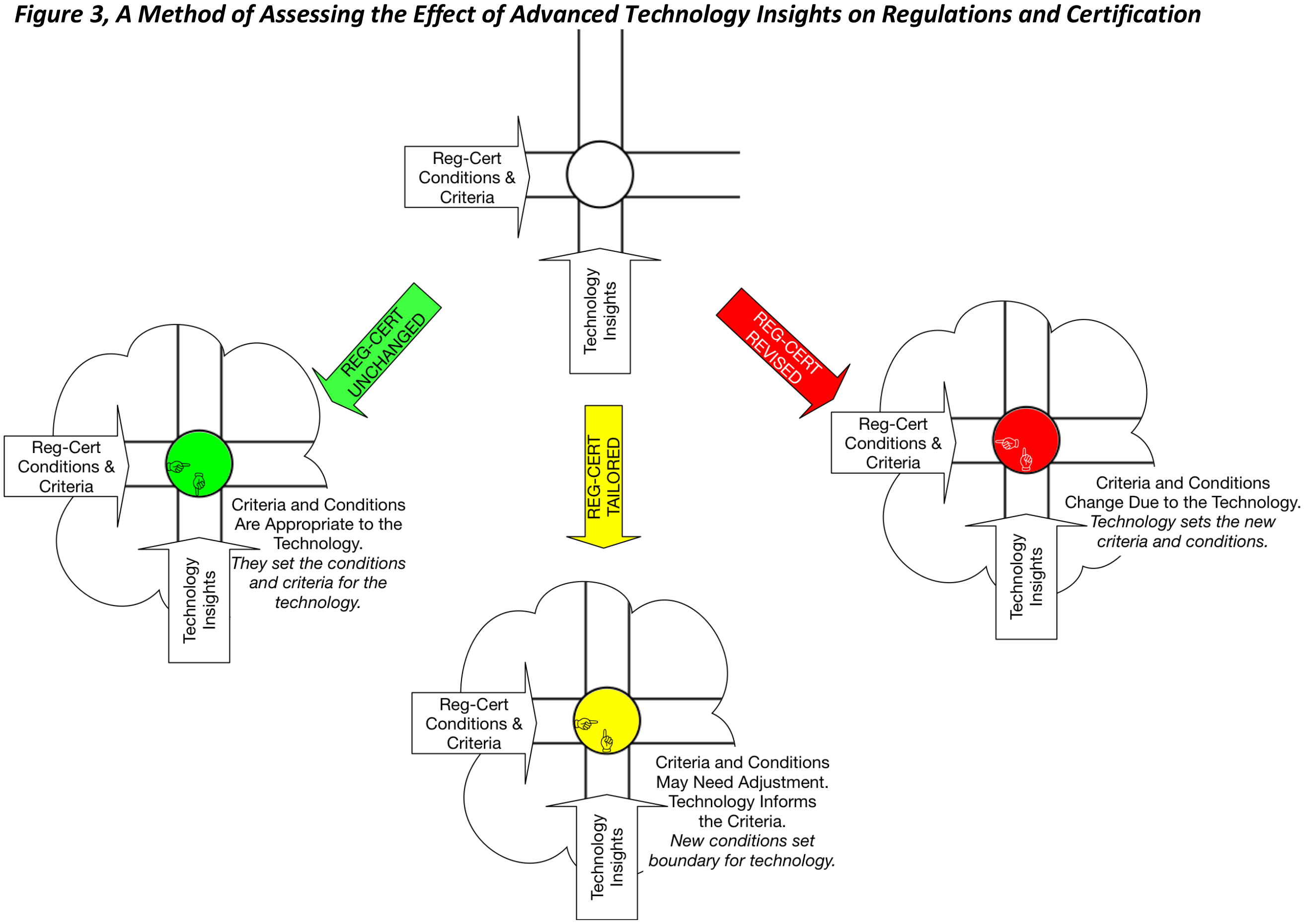


With this foundation, for the case of electric propulsion, the conversation is no longer a matter of completely new certification criteria, rather it becomes a discussion of understanding that which remains in certification practice for electric propulsion (for the benefit of the electric propulsion community, as well as the standards and certification authorities), and what is unique and, therefore, new.

Figure 3 describes the analysis that is necessary for each of the intersections in Figure 2, Integrating Regulations with Vehicle Concepts and the System Technology Demonstrator. There are fundamentally three conditions that will be examined: (1) the regulations and-or certification remains unchanged with the new technology; (2) the regulations and-or certification is tailored by the technology; and (3) the regulations and-or certification is revised.

In the first case, the criteria and conditions are appropriate to the technology, and they set the conditions and criteria for the technology. The second case, the criteria and conditions may need adjustment, as the technology informs the criteria, and once new conditions are set, they become the boundary for technology. Finally, the criteria and conditions are changed by the technology, and it is the technology that sets the new criteria and conditions.

Figure 3, A Method of Assessing the Effect of Advanced Technology Insights on Regulations and Certification



For this report, the part provided by each of the elements of the system technology demonstration phases will be provided by a surrogate of experts. This provides a means to set initial conditions for the elements in the regulatory-certification elements. Accordingly, the basis of this report will be to identify those candidate paragraphs in the Federal Aviation Regulations and the associated Means of Compliance that would be affected by new technology. And the new technology will be evaluated based on electric propulsion. This same approach can be applied to any new technology.

The following sections provide an overview the regulations (section 5) and then the means of compliance (sections 6 and 7). Finally, section 8 will examine an approach to identify those areas, with a focus on electric propulsion, where regulations can remain unchanged, require tailoring or require revision to accommodate electric propulsion technology.

A subsequent report will examine the elements of the system technology demonstration phases and their particular effect on the regulations, based on data from the NASA X-57 system technology development and demonstration.

5. Review the Current Regulations That Apply to Small Aircraft

The following tables show the requirements of the FAR 35 (Propellers), 33 (Engines) and 23 (Installation into Small Airplanes) regulations applicable to general aviation aircraft and reciprocating engines, along with notes showing the underlying expectations or requirements-drivers, highlighted. These regulations are from the online "Regulatory and Guidance Library"[6]. From these notes, one can set the stage for subsequent analysis of the applicability of these three Parts to electric propulsion.

5.1. Review of FAR 35 and Considerations to Electric Propulsion

It should be noted that almost all of the FAR 35 requirements[7], shown in Table 1, are applicable to electric propulsion systems that use propellers. Further for some vehicle concepts that use multiple propellers with an electric propulsion system, that some of the FAR 35 requirements are very important.

Table 1 - FAR 35, Airworthiness Standards: Propellers

Subpart	Section	Note
Subpart A—General		
	§35.1 Applicability.	… prescribes airworthiness standards for the issue of type certificates and changes to those certificates, for propellers

[6] "Regulatory and Guidance Library" http://rgl.faa.gov

[7] , Electronic Code of Federal Regulations, "PART 35—AIRWORTHINESS STANDARDS: PROPELLERS," https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=0f2b2017e4224fe33a8d03758c5806fd&pitd=20170830&n=pt14.1.35&r=PART&ty=HTML

Subpart	Section	Note
	§35.2 Propeller configuration.	… a list of all the components, including references to the relevant drawings and software design data, that define the type design of the propeller to be approved…
	§35.3 Instructions for propeller installation and operation.	
	§35.4 Instructions for Continued Airworthiness.	
	§35.5 Propeller ratings and operating limitations.	
	§35.7 Features and characteristics.	… The propeller may not have features or characteristics, revealed by any test or analysis or known to the applicant, that make it unsafe for the uses for which certification is requested.
Subpart B—Design and Construction		
	§35.15 Safety analysis.	… analyze the propeller system to assess the likely consequences of all failures that can reasonably be expected to occur…
	§35.16 Propeller critical parts.	The integrity of each propeller critical part identified by the safety analysis…
	§35.17 Materials and manufacturing methods.	
	§35.19 Durability.	Each part of the propeller must be designed and constructed to minimize the development of any unsafe condition of the propeller between overhaul periods.
	§35.21 Variable and reversible pitch propellers.	
	§35.22 Feathering propellers.	
	§35.23 Propeller control system.	

Subpart	Section	Note
	§35.24 Strength.	The maximum stresses developed in the propeller may not exceed values acceptable…
Subpart C—Tests and Inspections		
	§35.33 General.	Each applicant must furnish test article(s) and suitable testing facilities, including equipment and competent personnel, and conduct the required tests…
	§35.34 Inspections, adjustments and repairs.	
	§35.35 Centrifugal load tests.	…demonstrate that a propeller complies with paragraphs (a), (b) and (c) of this section without evidence of failure, malfunction, or permanent deformation that would result in a major or hazardous propeller effect. When the propeller could be sensitive to environmental degradation in service, this must be considered. (…not applicable to fixed-pitch wood or fixed-pitch metal propellers of conventional design.)
	§35.36 Bird impact.	…demonstrate, by tests or analysis based on tests or experience on similar designs, that the propeller can withstand the impact of a 4-pound bird at the critical location(s) and critical flight condition(s) of a typical installation without causing a major or hazardous propeller effect. (…not applicable to fixed-pitch wood or fixed-pitch metal propellers of conventional design.)
	§35.37 Fatigue limits and evaluation.	(…not applicable to fixed-pitch wood or fixed-pitch metal propellers of conventional design.)
	§35.38 Lightning strike.	(…not applicable to fixed-pitch wood or fixed-pitch metal propellers of conventional design.) … demonstrate, by tests, analysis based on tests, or experience on similar designs, that the propeller can withstand a lightning strike without causing a major or hazardous propeller effect.
	§35.39 Endurance test.	
	§35.40 Functional test.	… variable-pitch propeller system must be subjected to the applicable functional tests of this section. The same propeller system used in the endurance test (§35.39) must be used in the functional tests and must be driven by a representative engine on a test stand or on an airplane. The propeller must complete these tests without evidence of failure or malfunction.

Subpart	Section	Note
	§35.41 Overspeed and overtorque.	
	§35.42 Components of the propeller control system.	… demonstrate by tests, analysis based on tests, or service experience on similar components, that each propeller blade pitch control system component, including governors, pitch change assemblies, pitch locks, mechanical stops, and feathering system components, can withstand cyclic operation that simulates the normal load and pitch change travel to which the component would be subjected during the initially declared overhaul period or during a minimum of 1,000 hours of typical operation in service.
	§35.43 Propeller hydraulic components.	… show by test, validated analysis, or both, that propeller components that contain hydraulic pressure and whose structural failure or leakage from a structural failure could cause a hazardous propeller effect demonstrate structural integrity…
(Appendix A to Part 35—Instructions for Continued Airworthiness)		

5.2. Review of FAR 33, Reciprocating Engines, and Considerations to Electric Propulsion

For FAR 33, Reciprocating Engines[8], shown in Table 2, the applicability of the requirements to electric propulsion systems are not that clear-cut. While Subparts A and B seem to have fits with electric propulsion systems, the details within Subpart C, Design and Construction; Reciprocating Aircraft Engines, and the details within Subpart D, Block Test, deserve hard reviews. While §33.34 Turbocharger rotors, §33.35 Fuel and induction system, and §33.37 Ignition system, in Subpart C focuses on reciprocating engine and fuel, the remainder of Subpart C is applicable to electric propulsion systems. Analogies for §§33.35 and 33.37 may deserve some attention to electric propulsion systems. In Subpart D, it is clear that, for example, §33.47, Detonation Testing, is not applicable. The question becomes, however, is there an analogy to an internal combustion engine's tendency to detonate that should be considered for electric propulsion systems? Does an over excitation of an armature winding constitute the equivalent to detonation? Is it even a potentially hazardous condition? Perhaps not. And while the thermodynamic basis for engine structural integrity for the extensive Endurance Testing in §33.49 is not appropriate, is there a reason to test the endurance of an electric propulsion system? Probably yes. Accordingly, as inapplicable as Subparts C and D, may appear to electric propulsion, nonetheless these subparts deserve the attention of the electric propulsion system.

[8] Electronic Code of Federal Regulations, "PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES," https://www.ecfr.gov/cgi-bin/text-idx?SID=62a48f3dbbf9d94f5820238e86593597&pitd=20170830&tpl=/ecfrbrowse/Title14/14cfr33_main_02.tpl

While much of this report focuses on FAR 33 with respect to reciprocating engines, depending on the advanced technology begin applied in terms of energy storage, energy conversion, conversion of electrical power to run an electric motor, conversion to mechanical power, and the mechanical power to propulsion, there may be great safety benefit examining other parts of FAR 33 related to turbine engine certification (FAR 33, Subparts E, Design and Construction; Turbine Aircraft Engines, and F, Subpart F, Block Tests; Turbine Aircraft Engines).

Since this report focused on establishing a foundation by which to evaluate the methodology to the NASA X-57 “Maxwell” Distributed Electric Propulsion flight demonstrator as an example new aircraft technology, a more extensive examination is anticipated in a subsequent report.

Table 2 - FAR 33, Airworthiness Standards: Aircraft Engines

Subpart	Section	Note
Subpart A—General		
	§33.1 Applicability.	… prescribes airworthiness standards for the issue of type certificates and changes to those certificates, for aircraft engines.
	§33.3 General.	
	§33.4 Instructions for Continued Airworthiness.	… must prepare Instructions for Continued Airworthiness in accordance with appendix A to this part…
	§33.5 Instruction manual for installing and operating the engine.	… prior to the issuance of the type certificate, and to the owner at the time of delivery of the engine, approved instructions for installing and operating the engine…
	§33.7 Engine ratings and operating limitations.	(a) … included in the engine certificate data sheet specified in §21.41 of this chapter, including ratings and limitations based on the operating conditions and information specified… and any other information found necessary for safe operation of the engine.
		(b)(1) Horsepower or torque, r.p.m., manifold pressure, and time at critical pressure altitude and sea level pressure altitude for—(i) Rated maximum continuous power (relating to unsupercharged operation or to operation in each supercharger mode as applicable); and (ii) Rated takeoff power (relating to unsupercharged operation or to operation in each supercharger mode as applicable).
		(b)(2) Fuel grade or specification.
		(b)(3) Oil grade or specification.

Subpart	Section	Note
		(b)(4) Temperature of the—(i) Cylinder; (ii) Oil at the oil inlet; and (iii) Turbosupercharger turbine wheel inlet gas.
		(b)(5) Pressure of—(i) Fuel at the fuel inlet; and (ii) Oil at the main oil gallery.
		(b)(6) Accessory drive torque and overhang moment.
		(b)(7) Component life.
		(b)(8) Turbosupercharger turbine wheel r.p.m.
		(d) … the overall limits of accuracy of the engine control system and of the necessary instrumentation as defined in §33.5(a)(6)…
	§33.8 Selection of engine power and thrust ratings.	…Each [applicant-] selected rating must be for the lowest power or thrust that all engines of the same type may be expected to produce under the conditions used to determine that rating.
Subpart B—Design and Construction		
	§33.11 Applicability.	… prescribes the general design and construction requirements for reciprocating … aircraft engines
	§33.15 Materials.	… Conform to approved specifications (such as industry or military specifications) that ensure their having the strength and other properties assumed in the design data.
	§33.17 Fire protection.	… 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 failure conditions, and must minimize the effect of such a fire…
	§33.19 Durability.	(a) Engine design and construction must minimize the development of an unsafe condition of the engine between overhaul periods… (b) Each component of the propeller blade pitch control system which is a part of the engine type design must meet the requirements of §§35.21, 35.23, 35.42 and 35.43…
	§33.21 Engine cooling.	Engine design and construction must provide the necessary cooling under conditions in which the airplane is expected to operate.
	§33.23 Engine mounting attachments and structure.	… maximum allowable limit and ultimate loads for engine mounting attachments and related engine structure must be specified. …
	§33.25 Accessory attachments.	The engine must operate properly with the accessory drive and mounting attachments loaded. …

Subpart	Section	Note
	§33.27 Turbine, compressor, fan, and turbosupercharger rotor overspeed.	(a) For each fan, compressor, turbine, and turbosupercharger rotor, the applicant must establish by test, analysis, or a combination of both, that each rotor will not burst when operated in the engine for 5 minutes at whichever of the conditions defined in paragraph (b) of this section is the most critical with respect to the integrity of such a rotor. …
	§33.28 Engine control systems.	(a) Applicability. These requirements are applicable to any system or device that is part of engine type design, that controls, limits, or monitors engine operation, and is necessary for the continued airworthiness of the engine. … (b) Validation—(1) Functional aspects. … (2) Environmental limits. … (c) Control transitions. … (d) Engine control system failures. … (e) System safety assessment. … (f) Protection systems. … (g) Software. … (h) Aircraft-supplied data. … (i) Aircraft-supplied electrical power. … (j) Air pressure signal. … (k) Automatic availability and control of engine power for 30-second OEI rating. … (l) Engine shut down means. … (m) Programmable logic devices. …
	§33.29 Instrument connection.	(a) Unless it is constructed to prevent its connection to an incorrect instrument, each connection provided for powerplant instruments required by aircraft airworthiness regulations or necessary to insure operation of the engine in compliance with any engine limitation must be marked to identify it with its corresponding instrument. … (e) The applicant must make provision for the installation of instrumentation necessary to ensure operation in compliance with engine operating limitations. Where, in presenting the safety analysis, or complying with any other requirement, dependence is placed on instrumentation that is not otherwise mandatory in the assumed aircraft installation, then the applicant must specify this instrumentation in the engine installation instructions and declare it mandatory in the engine approval documentation. (f) As part of the System Safety Assessment of §33.28(e), the applicant must assess the possibility and subsequent effect of incorrect fit of instruments, sensors, or connectors. Where necessary, the applicant must take design precautions to prevent incorrect configuration of the system. …
Subpart C—Design and Construction; Reciprocating Aircraft Engines		
	§33.31 Applicability.	… prescribes additional design and construction requirements for reciprocating aircraft engines.
	§33.33 Vibration.	The engine must be designed and constructed to function throughout its normal operating range of crankshaft rotational speeds and engine powers without inducing excessive stress in any of the engine parts because of vibration and without imparting excessive vibration forces to the aircraft structure.

Subpart	Section	Note
	§33.34 Turbocharger rotors.	Each turbocharger case must be designed and constructed to be able to contain fragments of a compressor or turbine that fails at the highest speed that is obtainable with normal speed control devices inoperative.
	§33.35 Fuel and induction system.	(a) The fuel system of the engine must be designed and constructed to supply an appropriate mixture of fuel to the cylinders throughout the complete operating range of the engine under all flight and atmospheric conditions. …
	§33.37 Ignition system.	Each spark ignition engine must have a dual ignition system with at least two spark plugs for each cylinder and two separate electric circuits with separate sources of electrical energy, or have an ignition system of equivalent in-flight reliability.
	§33.39 Lubrication system.	(a) The lubrication system of the engine must be designed and constructed so that it will function properly in all flight attitudes and atmospheric conditions in which the airplane is expected to operate. In wet sump engines, this requirement must be met when only one-half of the maximum lubricant supply is in the engine. ¶ (b) The lubrication system of the engine must be designed and constructed to allow installing a means of cooling the lubricant. ¶ (c) The crankcase must be vented to the atmosphere to preclude leakage of oil from excessive pressure in the crankcase.
Subpart D—Block Tests; Reciprocating Aircraft Engines		
	§33.41 Applicability.	… prescribes the block tests and inspections for reciprocating aircraft engines.
	§33.42 General.	Before each endurance test required by this subpart, the adjustment setting and functioning characteristic of each component having an adjustment setting and a functioning characteristic that can be established independent of installation on the engine must be established and recorded.

Subpart	Section	Note
	§33.43 Vibration test.	(a) Each engine must undergo a vibration survey to establish the torsional and bending vibration characteristics of the crankshaft and the propeller shaft or other output shaft, over the range of crankshaft speed and engine power, under steady state and transient conditions, from idling speed to either 110 percent of the desired maximum continuous speed rating or 103 percent of the maximum desired takeoff speed rating, whichever is higher. The survey must be conducted using, for airplane engines, the same configuration of the propeller type which is used for the endurance test, and using, for other engines, the same configuration of the loading device type which is used for the endurance test. ¶ (b) The torsional and bending vibration stresses of the crankshaft and the propeller shaft or other output shaft may not exceed the endurance limit stress of the material from which the shaft is made. If the maximum stress in the shaft cannot be shown to be below the endurance limit by measurement, the vibration frequency and amplitude must be measured. The peak amplitude must be shown to produce a stress below the endurance limit; if not, the engine must be run at the condition producing the peak amplitude until, for steel shafts, 10 million stress reversals have been sustained without fatigue failure and, for other shafts, until it is shown that fatigue will not occur within the endurance limit stress of the material. ¶ (c) Each accessory drive and mounting attachment must be loaded, with the loads imposed by each accessory used only for an aircraft service being the limit load specified by the applicant for the drive or attachment point. ¶ (d) The vibration survey described in paragraph (a) of this section must be repeated with that cylinder not firing which has the most adverse vibration effect, in order to establish the conditions under which the engine can be operated safely in that abnormal state. However, for this vibration survey, the engine speed range need only extend from idle to the maximum desired takeoff speed, and compliance with paragraph (b) of this section need not be shown.
	§33.45 Calibration tests.	(a) Each engine must be subjected to the calibration tests necessary to establish its power characteristics and the conditions for the endurance test specified in §33.49. The results of the power characteristics calibration tests form the basis for establishing the characteristics of the engine over its entire operating range of crankshaft rotational speeds, manifold pressures, fuel/air mixture settings, and altitudes. Power ratings are based upon standard atmospheric conditions with only those accessories installed which are essential for engine functioning. ¶ (b) A power check at sea level conditions must be accomplished on the endurance test engine after the endurance test. Any change in power characteristics which occurs during the endurance test must be determined. Measurements taken during the final portion of the endurance test may be used in showing compliance with the requirements of this paragraph.
	§33.47 Detonation test.	Each engine must be tested to establish that the engine can function without detonation throughout its range of intended conditions of operation.

Subpart	Section	Note
	§33.49 Endurance test.	(a) General. Each engine must be subjected to an endurance test that includes a total of 150 hours of operation (except as provided in paragraph (e)(1)(iii) of this section) and, depending upon the type and contemplated use of the engine, consists of one of the series of runs specified in paragraphs (b) through (e) of this section, as applicable. The runs must be made in the order found appropriate … for the particular engine being tested. During the endurance test the engine power and the crankshaft rotational speed must be kept within ±3 percent of the rated values. During the runs at rated takeoff power and for at least 35 hours at rated maximum continuous power, one cylinder must be operated at not less than the limiting temperature, the other cylinders must be operated at a temperature not lower than 50°F. below the limiting temperature, and the oil inlet temperature must be maintained within ±10°F. of the limiting temperature. An engine that is equipped with a propeller shaft must be fitted for the endurance test with a propeller that thrust-loads the engine to the maximum thrust which the engine is designed to resist at each applicable operating condition specified in this section. Each accessory drive and mounting attachment must be loaded. During operation at rated takeoff power and rated maximum continuous power, the load imposed by each accessory used only for an aircraft service must be the limit load specified by the applicant for the engine drive or attachment point. ¶ (b) Unsupercharged engines and engines incorporating a gear-driven single-speed supercharger. … ¶ (c) Engines incorporating a gear-driven two-speed supercharger. … ¶ (d) Helicopter engines. … ¶ (e) Turbosupercharged engines. …
	§33.51 Operation test.	… operation test must include the testing … to demonstrate backfire characteristics, starting, idling, acceleration, overspeeding, functioning of propeller and ignition, and any other operational characteristic of the engine. If the engine incorporates a multispeed supercharger drive, the design and construction must allow the supercharger to be shifted from operation at the lower speed ratio to the higher and the power appropriate to the manifold pressure and speed settings for rated maximum continuous power at the higher supercharger speed ratio must be obtainable within five seconds.
	§33.53 Engine system and component tests.	(a) For those systems and components that cannot be adequately substantiated in accordance with endurance testing of §33.49, the applicant must conduct additional tests to demonstrate that systems or components are able to perform the intended functions in all declared environmental and operating conditions. ¶ (b) Temperature limits must be established for each component that requires temperature controlling provisions in the aircraft installation to assure satisfactory functioning, reliability, and durability.

Subpart	Section	Note
	§33.55 Teardown inspection.	After completing the endurance test— ¶ (a) Each engine must be completely disassembled; ¶ (b) Each component having an adjustment setting and a functioning characteristic that can be established independent of installation on the engine must retain each setting and functioning characteristic within the limits that were established and recorded at the beginning of the test; and ¶ (c) Each engine component must conform to the type design and be eligible for incorporation into an engine for continued operation, in accordance with information submitted in compliance with §33.4.
	§33.57 General conduct of block tests.	(a) The applicant may, in conducting the block tests, use separate engines of identical design and construction in the vibration, calibration, detonation, endurance, and operation tests, except that, if a separate engine is used for the endurance test it must be subjected to a calibration check before starting the endurance test. ¶ (b) The applicant may service and make minor repairs to the engine during the block tests in accordance with the service and maintenance instructions submitted in compliance with §33.4. If the frequency of the service is excessive, or the number of stops due to engine malfunction is excessive, or a major repair, or replacement of a part is found necessary during the block tests or as the result of findings from the teardown inspection, the engine or its parts may be subjected to any additional test … necessary. ¶ (c) Each applicant must furnish all testing facilities, including equipment and competent personnel, to conduct the block tests.
Appendix A to Part 33—Instructions for Continued Airworthiness		

5.3. Review of FAR 23, Normal Category Airplanes, and Considerations to Electric Propulsion

There are seven subparts to the current FAR 23, "Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes." They are:

- Subpart A—General
- Subpart B—Flight
- Subpart C—Structures
- Subpart D—Design and Construction
- Subpart E—Powerplant
- Subpart F—Equipment
- Subpart G—Flightcrew Interface and Other Information

Preceding Subpart A, General, there are three sections referenced in FAR 23, and those are §§ 23.1457, Cockpit voice recorders; 23.1459, Flight data recorders; and 23.1529, Instructions for continued airworthiness. These three sections are expected to be met without modification for electric propulsion.

While the focus of the electric propulsion effort resides, primarily, in Subpart E, Propulsion, the other subparts of FAR 23 are reviewed.

5.3.1. Review of Normal Category Airplanes, Subpart A, General

Subpart A, General, shown in Table 3, provides the context for the certification for the aircraft. In particular it specifies the applicable vehicle weight and passenger seating, and then sets the levels associated with the certification. Of note is *"§23.2410 Powerplant installation hazard assessment"* and its general note of the means of compliance.

Table 3, FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart A, General

Subpart	Section	Note
Subpart A—General		
	§ 23.2000 Applicability and definitions.	(a) This part prescribes airworthiness standards for the issuance of type certificates, and changes to those certificates, for airplanes in the normal category.
		(b) For the purposes of this part, the following definition applies: Continued safe flight and landing means an airplane is capable of continued controlled flight and landing, possibly using emergency procedures, without requiring exceptional pilot skill or strength. Upon landing, some airplane damage may occur as a result of a failure condition.
	§23.2005 Certification of normal category airplanes.	(a) Certification in the normal category applies to airplanes with a passenger-seating configuration of 19 or less and a maximum certificated takeoff weight of 19,000 pounds or less.
		(b) Airplane certification levels are: (1) Level 1—for airplanes with a maximum seating configuration of 0 to 1 passengers. ¶ (2) Level 2—for airplanes with a maximum seating configuration of 2 to 6 passengers. ¶ (3) Level 3—for airplanes with a maximum seating configuration of 7 to 9 passengers. ¶ (4) Level 4—for airplanes with a maximum seating configuration of 10 to 19 passengers.
		(c) Airplane performance levels are: (1) Low speed—for airplanes with a VNO and VMO ≤ 250 Knots Calibrated Airspeed (KCAS) and a MMO ≤ 0.6. ¶ (2) High speed—for airplanes with a VNO or VMO > 250 KCAS or a MMO > 0.6.
		(d) Airplanes not certified for aerobatics may be used to perform any maneuver incident to normal flying, including— (1) Stalls (except whip stalls); and (2) Lazy eights, chandelles, and steep turns, in which the angle of bank is not more than 60 degrees.

Subpart	Section	Note
	§23.2410 Powerplant installation hazard assessment.	(a) An applicant must comply with this part using a means of compliance, which may include consensus standards, accepted by the Administrator.
		(b) An applicant requesting acceptance of a means of compliance must provide the means of compliance to the FAA in a form and manner acceptable to the Administrator.

5.3.2. Review of Normal Category Airplanes, Subpart B, Flight

Subpart B, Flight, shown in Table 4, describes the performance and flight characteristics to which the aircraft must conform. Performance, of course, is associated most closely with propulsion systems, and thus references in §23.2110 Stall speed; §23.2115 Takeoff performance; §23.2120 Climb requirements; and §23.2125 Climb information.

Table 4, FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart B, Flight

Subpart	Section	Note
Subpart B—Flight		
Performance		
	§23.2100 Weight and center of gravity.	(a) The applicant must determine limits for weights and centers of gravity that provide for the safe operation of the airplane.
		(b) The applicant must comply with each requirement of this subpart at critical combinations of weight and center of gravity within the airplane's range of loading conditions using tolerances acceptable to the Administrator.
		(c) The condition of the airplane at the time of determining its empty weight and center of gravity must be well defined and easily repeatable.
	§23.2105 Performance data.	(a) Unless otherwise prescribed, an airplane must meet the performance requirements of this subpart in— (1) Still air and standard atmospheric conditions at sea level for all airplanes; and (2) Ambient atmospheric conditions within the operating envelope for levels 1 and 2 high-speed and levels 3 and 4 airplanes.

Subpart	Section	Note
		(b) Unless otherwise prescribed, the applicant must develop the performance data required by this subpart for the following conditions: (1) Airport altitudes from sea level to 10,000 feet (3,048 meters); and (2) Temperatures above and below standard day temperature that are within the range of operating limitations, if those temperatures could have a negative effect on performance.
		(c) The procedures used for determining takeoff and landing distances must be executable consistently by pilots of average skill in atmospheric conditions expected to be encountered in service.
		(d) Performance data determined in accordance with paragraph (b) of this section must account for losses due to atmospheric conditions, cooling needs, and other demands on power sources.
	§23.2110 Stall speed.	The applicant must determine the airplane stall speed or the minimum steady flight speed for each flight configuration used in normal operations, including takeoff, climb, cruise, descent, approach, and landing. The stall speed or minimum steady flight speed determination must account for the most adverse conditions for each flight configuration with power set at—
		(a) Idle or zero thrust for propulsion systems that are used primarily for thrust; and
		(b) A nominal thrust for propulsion systems that are used for thrust, flight control, and/or high-lift systems.
	§23.2115 Takeoff performance.	(a) The applicant must determine airplane takeoff performance accounting for— (1) Stall speed safety margins; (2) Minimum control speeds; and (3) Climb gradients.
		(b) For single engine airplanes and levels 1, 2, and 3 low-speed multiengine airplanes, takeoff performance includes the determination of ground roll and initial climb distance to 50 feet (15 meters) above the takeoff surface.
		(c) For levels 1, 2, and 3 high-speed multiengine airplanes, and level 4 multiengine airplanes, takeoff performance includes a determination the following distances after a sudden critical loss of thrust— (1) An aborted takeoff at critical speed; (2) Ground roll and initial climb to 35 feet (11 meters) above the takeoff surface; and (3) Net takeoff flight path.
	§23.2120 Climb requirements.	The design must comply with the following minimum climb performance out of ground effect:

Subpart	Section	Note
		(a) With all engines operating and in the initial climb configuration— (1) For levels 1 and 2 low-speed airplanes, a climb gradient of 8.3 percent for landplanes and 6.7 percent for seaplanes and amphibians; and (2) For levels 1 and 2 high-speed airplanes, all level 3 airplanes, and level 4 single-engines a climb gradient after takeoff of 4 percent.
		(b) After a critical loss of thrust on multiengine airplanes— (1) For levels 1 and 2 low-speed airplanes that do not meet single-engine crashworthiness requirements, a climb gradient of 1.5 percent at a pressure altitude of 5,000 feet (1,524 meters) in the cruise configuration(s); (2) For levels 1 and 2 high-speed airplanes, and level 3 low-speed airplanes, a 1 percent climb gradient at 400 feet (122 meters) above the takeoff surface with the landing gear retracted and flaps in the takeoff configuration(s); and (3) For level 3 high-speed airplanes and all level 4 airplanes, a 2 percent climb gradient at 400 feet (122 meters) above the takeoff surface with the landing gear retracted and flaps in the approach configuration(s).
		(c) For a balked landing, a climb gradient of 3 percent without creating undue pilot workload with the landing gear extended and flaps in the landing configuration(s).
	§23.2125 Climb information.	(a) The applicant must determine climb performance at each weight, altitude, and ambient temperature within the operating limitations— (1) For all single-engine airplanes; (2) For levels 1 and 2 high-speed multiengine airplanes and level 3 multiengine airplanes, following a critical loss of thrust on takeoff in the initial climb configuration; and (3) For all multiengine airplanes, during the enroute phase of flight with all engines operating and after a critical loss of thrust in the cruise configuration.
		(b) The applicant must determine the glide performance for single-engine airplanes after a complete loss of thrust.
	§23.2130 Landing.	The applicant must determine the following, for standard temperatures at critical combinations of weight and altitude within the operational limits:
		(a) The distance, starting from a height of 50 feet (15 meters) above the landing surface, required to land and come to a stop.
		(b) The approach and landing speeds, configurations, and procedures, which allow a pilot of average skill to land within the published landing distance consistently and without causing damage or injury, and which allow for a safe transition to the balked landing conditions of this part accounting for: (1) Stall speed safety margin; and (2) Minimum control speeds.

Subpart	Section	Note
Flight Characteristics		
	§23.2135 Controllability.	(a) The airplane must be controllable and maneuverable, without requiring exceptional piloting skill, alertness, or strength, within the operating envelope— (1) At all loading conditions for which certification is requested; (2) During all phases of flight; (3) With likely reversible flight control or propulsion system failure; and (4) During configuration changes.
		(b) The airplane must be able to complete a landing without causing substantial damage or serious injury using the steepest approved approach gradient procedures and providing a reasonable margin below Vref or above approach angle of attack.
		(c) VMC is the calibrated airspeed at which, following the sudden critical loss of thrust, it is possible to maintain control of the airplane. For multiengine airplanes, the applicant must determine VMC, if applicable, for the most critical configurations used in takeoff and landing operations.
		(d) If the applicant requests certification of an airplane for aerobatics, the applicant must demonstrate those aerobatic maneuvers for which certification is requested and determine entry speeds.
	§23.2140 Trim.	(a) The airplane must maintain lateral and directional trim without further force upon, or movement of, the primary flight controls or corresponding trim controls by the pilot, or the flight control system, under the following conditions: (1) For levels 1, 2, and 3 airplanes in cruise. (2) For level 4 airplanes in normal operations.
		(b) The airplane must maintain longitudinal trim without further force upon, or movement of, the primary flight controls or corresponding trim controls by the pilot, or the flight control system, under the following conditions: (1) Climb. (2) Level flight. (3) Descent. (4) Approach.
		(c) Residual control forces must not fatigue or distract the pilot during normal operations of the airplane and likely abnormal or emergency operations, including a critical loss of thrust on multiengine airplanes.
	§23.2145 Stability.	(a) Airplanes not certified for aerobatics must— (1) Have static longitudinal, lateral, and directional stability in normal operations; (2) Have dynamic short period and Dutch roll stability in normal operations; and (3) Provide stable control force feedback throughout the operating envelope.
		(b) No airplane may exhibit any divergent longitudinal stability characteristic so unstable as to increase the pilot's workload or otherwise endanger the airplane and its occupants.

Subpart	Section	Note
	§23.2150 Stall characteristics, stall warning, and spins.	(a) The airplane must have controllable stall characteristics in straight flight, turning flight, and accelerated turning flight with a clear and distinctive stall warning that provides sufficient margin to prevent inadvertent stalling.
		(b) Single-engine airplanes, not certified for aerobatics, must not have a tendency to inadvertently depart controlled flight.
		(c) Levels 1 and 2 multiengine airplanes, not certified for aerobatics, must not have a tendency to inadvertently depart controlled flight from thrust asymmetry after a critical loss of thrust.
		(d) Airplanes certified for aerobatics that include spins must have controllable stall characteristics and the ability to recover within one and one-half additional turns after initiation of the first control action from any point in a spin, not exceeding six turns or any greater number of turns for which certification is requested, while remaining within the operating limitations of the airplane.
		(e) Spin characteristics in airplanes certified for aerobatics that includes spins must recover without exceeding limitations and may not result in unrecoverable spins— (1) With any typical use of the flight or engine power controls; or (2) Due to pilot disorientation or incapacitation.
	§23.2155 Ground and water handling characteristics.	For airplanes intended for operation on land or water, the airplane must have controllable longitudinal and directional handling characteristics during taxi, takeoff, and landing operations.
	§23.2160 Vibration, buffeting, and high-speed characteristics.	(a) Vibration and buffeting, for operations up to VD/MD, must not interfere with the control of the airplane or cause excessive fatigue to the flightcrew. Stall warning buffet within these limits is allowable.
		(b) For high-speed airplanes and all airplanes with a maximum operating altitude greater than 25,000 feet (7,620 meters) pressure altitude, there must be no perceptible buffeting in cruise configuration at 1g and at any speed up to VMO/MMO, except stall buffeting.
		(c) For high-speed airplanes, the applicant must determine the positive maneuvering load factors at which the onset of perceptible buffet occurs in the cruise configuration within the operational envelope. Likely inadvertent excursions beyond this boundary must not result in structural damage.

Subpart	Section	Note
		(d) High-speed airplanes must have recovery characteristics that do not result in structural damage or loss of control, beginning at any likely speed up to VMO/MMO, following— (1) An inadvertent speed increase; and (2) A high-speed trim upset for airplanes where dynamic pressure can impair the longitudinal trim system operation.
	§23.2165 Performance and flight characteristics requirements for flight in icing conditions.	(a) An applicant who requests certification for flight in icing conditions defined in part 1 of appendix C to part 25 of this chapter, or an applicant who requests certification for flight in these icing conditions and any additional atmospheric icing conditions, must show the following in the icing conditions for which certification is requested under normal operation of the ice protection system(s): (1) Compliance with each requirement of this subpart, except those applicable to spins and any that must be demonstrated at speeds in excess of— (i) 250 knots CAS; (ii) VMO/MMO or VNE; or (iii) A speed at which the applicant demonstrates the airframe will be free of ice accretion. (2) The means by which stall warning is provided to the pilot for flight in icing conditions and non-icing conditions is the same.
		(b) If an applicant requests certification for flight in icing conditions, the applicant must provide a means to detect any icing conditions for which certification is not requested and show the airplane's ability to avoid or exit those conditions.
		(c) The applicant must develop an operating limitation to prohibit intentional flight, including takeoff and landing, into icing conditions for which the airplane is not certified to operate.

5.3.3. Review of Normal Category Airplanes, Subpart C, Structures

Subpart C, Structures, shown in Table 5, describes the structural loads; structural performance; design; and structural occupant protection to which the aircraft must conform. In structural loads section, §23.2225 Component loading conditions, describes structural load testing not only based on propulsion system operation in concert with flight gust and maneuver loads, but also sudden powerplant stoppage. In structural performance, §23.2240 Structural durability, paragraph (d) describes minimizing hazard due to high-energy fragments from an uncontained engine or rotating machinery failure. While this is typically focused on turbomachinery failure testing, consideration should be reviewed for electric propulsion systems, as well. In structural occupant protection, §23.2270 Emergency conditions, paragraph (a)(3) describes occupant protection against “items of mass” that could cause injury during an emergency landing.

Table 5, FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart C, Structures

Subpart	Section	Note
Subpart C—Structures		
	§23.2200 Structural design envelope.	The applicant must determine the structural design envelope, which describes the range and limits of airplane design and operational parameters for which the applicant will show compliance with the requirements of this subpart. The applicant must account for all airplane design and operational parameters that affect structural loads, strength, durability, and aeroelasticity, including:
		(a) Structural design airspeeds, landing descent speeds, and any other airspeed limitation at which the applicant must show compliance to the requirements of this subpart. The structural design airspeeds must— (1) Be sufficiently greater than the stalling speed of the airplane to safeguard against loss of control in turbulent air; and (2) Provide sufficient margin for the establishment of practical operational limiting airspeeds.
		(b) Design maneuvering load factors not less than those, which service history shows, may occur within the structural design envelope.
		(c) Inertial properties including weight, center of gravity, and mass moments of inertia, accounting for— (1) Each critical weight from the airplane empty weight to the maximum weight; and (2) The weight and distribution of occupants, payload, and fuel.
		(d) Characteristics of airplane control systems, including range of motion and tolerances for control surfaces, high lift devices, or other moveable surfaces.
		(e) Each critical altitude up to the maximum altitude.
	§23.2205 Interaction of systems and structures.	For airplanes equipped with systems that modify structural performance, alleviate the impact of this subpart's requirements, or provide a means of compliance with this subpart, the applicant must account for the influence and failure of these systems when showing compliance with the requirements of this subpart.
Structural Loads		
	§23.2210 Structural design loads.	(a) The applicant must: (1) Determine the applicable structural design loads resulting from likely externally or internally applied pressures, forces, or moments that may occur in flight, ground and water operations, ground and water handling, and while the airplane is parked or moored. (2) Determine the loads required by paragraph (a)(1) of this section at all critical combinations of parameters, on and within the boundaries of the structural design envelope.

Subpart	Section	Note
		(b) The magnitude and distribution of the applicable structural design loads required by this section must be based on physical principles.
	§23.2215 Flight load conditions.	The applicant must determine the structural design loads resulting from the following flight conditions:
		(a) Atmospheric gusts where the magnitude and gradient of these gusts are based on measured gust statistics.
		(b) Symmetric and asymmetric maneuvers.
		(c) Asymmetric thrust resulting from the failure of a powerplant unit.
	§23.2220 Ground and water load conditions.	The applicant must determine the structural design loads resulting from taxi, takeoff, landing, and handling conditions on the applicable surface in normal and adverse attitudes and configurations.
	§23.2225 Component loading conditions.	The applicant must determine the structural design loads acting on:
		(a) Each engine mount and its supporting structure such that both are designed to withstand loads resulting from— (1) Powerplant operation combined with flight gust and maneuver loads; and (2) For non-reciprocating powerplants, sudden powerplant stoppage.
		(b) Each flight control and high-lift surface, their associated system and supporting structure resulting from— (1) The inertia of each surface and mass balance attachment; (2) Flight gusts and maneuvers; (3) Pilot or automated system inputs; (4) System induced conditions, including jamming and friction; and (5) Taxi, takeoff, and landing operations on the applicable surface, including downwind taxi and gusts occurring on the applicable surface.
		(c) A pressurized cabin resulting from the pressurization differential— (1) From zero up to the maximum relief pressure combined with gust and maneuver loads; (2) From zero up to the maximum relief pressure combined with ground and water loads if the airplane may land with the cabin pressurized; and (3) At the maximum relief pressure multiplied by 1.33, omitting all other loads.
	§23.2230 Limit and ultimate loads.	The applicant must determine—
		(a) The limit loads, which are equal to the structural design loads unless otherwise specified elsewhere in this part; and

Subpart	Section	Note
		(b) The ultimate loads, which are equal to the limit loads multiplied by a 1.5 factor of safety unless otherwise specified elsewhere in this part.
Structural Performance		
	§23.2235 Structural strength.	The structure must support:
		(a) Limit loads without— (1) Interference with the safe operation of the airplane; and (2) Detrimental permanent deformation.
		(b) Ultimate loads.
	§23.2240 Structural durability.	(a) The applicant must develop and implement inspections or other procedures to prevent structural failures due to foreseeable causes of strength degradation, which could result in serious or fatal injuries, or extended periods of operation with reduced safety margins. Each of the inspections or other procedures developed under this section must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by §23.1529.
		(b) For Level 4 airplanes, the procedures developed for compliance with paragraph (a) of this section must be capable of detecting structural damage before the damage could result in structural failure.
		(c) For pressurized airplanes: (1) The airplane must be capable of continued safe flight and landing following a sudden release of cabin pressure, including sudden releases caused by door and window failures. (2) For airplanes with maximum operating altitude greater than 41,000 feet, the procedures developed for compliance with paragraph (a) of this section must be capable of detecting damage to the pressurized cabin structure before the damage could result in rapid decompression that would result in serious or fatal injuries.
		(d) The airplane must be designed to minimize hazards to the airplane due to structural damage caused by high-energy fragments from an uncontained engine or rotating machinery failure.
	§23.2245 Aeroelasticity.	(a) The airplane must be free from flutter, control reversal, and divergence—(1) At all speeds within and sufficiently beyond the structural design envelope; (2) For any configuration and condition of operation; (3) Accounting for critical degrees of freedom; and (4) Accounting for any critical failures or malfunctions.
		(b) The applicant must establish tolerances for all quantities that affect flutter.

Subpart	Section	Note
Design		
	§23.2250 Design and construction principles.	(a) The applicant must design each part, article, and assembly for the expected operating conditions of the airplane.
		(b) Design data must adequately define the part, article, or assembly configuration, its design features, and any materials and processes used.
		(c) The applicant must determine the suitability of each design detail and part having an important bearing on safety in operations.
		(d) The control system must be free from jamming, excessive friction, and excessive deflection when the airplane is subjected to expected limit airloads.
		(e) Doors, canopies, and exits must be protected against inadvertent opening in flight, unless shown to create no hazard when opened in flight.
	§23.2255 Protection of structure.	(a) The applicant must protect each part of the airplane, including small parts such as fasteners, against deterioration or loss of strength due to any cause likely to occur in the expected operational environment.
		(b) Each part of the airplane must have adequate provisions for ventilation and drainage.
		(c) For each part that requires maintenance, preventive maintenance, or servicing, the applicant must incorporate a means into the aircraft design to allow such actions to be accomplished.
	§23.2260 Materials and processes.	(a) The applicant must determine the suitability and durability of materials used for parts, articles, and assemblies, accounting for the effects of likely environmental conditions expected in service, the failure of which could prevent continued safe flight and landing.
		(b) The methods and processes of fabrication and assembly used must produce consistently sound structures. If a fabrication process requires close control to reach this objective, the applicant must perform the process under an approved process specification.
		(c) Except as provided in paragraphs (f) and (g) of this section, the applicant must select design values that ensure material strength with probabilities that account for the criticality of the structural element. Design values must account for the probability of structural failure due to material variability.

Subpart	Section	Note
		(d) If material strength properties are required, a determination of those properties must be based on sufficient tests of material meeting specifications to establish design values on a statistical basis.
		(e) If thermal effects are significant on a critical component or structure under normal operating conditions, the applicant must determine those effects on allowable stresses used for design.
		(f) Design values, greater than the minimums specified by this section, may be used, where only guaranteed minimum values are normally allowed, if a specimen of each individual item is tested before use to determine that the actual strength properties of that particular item will equal or exceed those used in the design.
		(g) An applicant may use other material design values if approved by the Administrator.
	§23.2265 Special factors of safety.	(a) The applicant must determine a special factor of safety for each critical design value for each part, article, or assembly for which that critical design value is uncertain, and for each part, article, or assembly that is— (1) Likely to deteriorate in service before normal replacement; or (2) Subject to appreciable variability because of uncertainties in manufacturing processes or inspection methods.
		(b) The applicant must determine a special factor of safety using quality controls and specifications that account for each— (1) Type of application; (2) Inspection method; (3) Structural test requirement; (4) Sampling percentage; and (5) Process and material control.
		(c) The applicant must multiply the highest pertinent special factor of safety in the design for each part of the structure by each limit and ultimate load, or ultimate load only, if there is no corresponding limit load, such as occurs with emergency condition loading.
Structural Occupant Protection		
	§23.2270 Emergency conditions.	(a) The airplane, even when damaged in an emergency landing, must protect each occupant against injury that would preclude egress when— (1) Properly using safety equipment and features provided for in the design; (2) The occupant experiences ultimate static inertia loads likely to occur in an emergency landing; and (3) Items of mass, including engines or auxiliary power units (APUs), within or aft of the cabin, that could injure an occupant, experience ultimate static inertia loads likely to occur in an emergency landing.

Subpart	Section	Note
		(b) The emergency landing conditions specified in paragraph (a)(1) and (a)(2) of this section, must— (1) Include dynamic conditions that are likely to occur in an emergency landing; and (2) Not generate loads experienced by the occupants, which exceed established human injury criteria for human tolerance due to restraint or contact with objects in the airplane.
		(c) The airplane must provide protection for all occupants, accounting for likely flight, ground, and emergency landing conditions.
		(d) Each occupant protection system must perform its intended function and not create a hazard that could cause a secondary injury to an occupant. The occupant protection system must not prevent occupant egress or interfere with the operation of the airplane when not in use.
		(e) Each baggage and cargo compartment must— (1) Be designed for its maximum weight of contents and for the critical load distributions at the maximum load factors corresponding to the flight and ground load conditions determined under this part; (2) Have a means to prevent the contents of the compartment from becoming a hazard by impacting occupants or shifting; and (3) Protect any controls, wiring, lines, equipment, or accessories whose damage or failure would affect safe operations.

5.3.4. Review of Normal Category Airplanes, Subpart D, Design and Construction

Subpart D, Design and Construction, shown in Table 6, focuses on occupant system design protection; and fire and high energy protection to which the aircraft must conform. While there are no overt references to propulsion systems, there are references to practices that minimize flammability concerns, and thus some consideration for battery safety should be considered.

Table 6, FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart D, Design and Construction

Subpart	Section	Note
Subpart D—Design and Construction		
	§23.2300 Flight control systems.	(a) The applicant must design airplane flight control systems to: (1) Operate easily, smoothly, and positively enough to allow proper performance of their functions. (2) Protect against likely hazards.

Subpart	Section	Note
		(b) The applicant must design trim systems, if installed, to: (1) Protect against inadvertent, incorrect, or abrupt trim operation. (2) Provide a means to indicate— (i) The direction of trim control movement relative to airplane motion; (ii) The trim position with respect to the trim range; (iii) The neutral position for lateral and directional trim; and (iv) The range for takeoff for all applicant requested center of gravity ranges and configurations.
	§23.2305 Landing gear systems.	(a) The landing gear must be designed to— (1) Provide stable support and control to the airplane during surface operation; and (2) Account for likely system failures and likely operation environments (including anticipated limitation exceedances and emergency procedures).
		(b) All airplanes must have a reliable means of stopping the airplane with sufficient kinetic energy absorption to account for landing. Airplanes that are required to demonstrate aborted takeoff capability must account for this additional kinetic energy.
		(c) For airplanes that have a system that actuates the landing gear, there is— (1) A positive means to keep the landing gear in the landing position; and (2) An alternative means available to bring the landing gear in the landing position when a non-deployed system position would be a hazard.
	§23.2310 Buoyancy for seaplanes and amphibians.	Airplanes intended for operations on water, must—
		(a) Provide buoyancy of 80 percent in excess of the buoyancy required to support the maximum weight of the airplane in fresh water; and
		(b) Have sufficient margin so the airplane will stay afloat at rest in calm water without capsizing in case of a likely float or hull flooding.
Occupant System Design Protection		
	§23.2315 Means of egress and emergency exits.	(a) With the cabin configured for takeoff or landing, the airplane is designed to: (1) Facilitate rapid and safe evacuation of the airplane in conditions likely to occur following an emergency landing, excluding ditching for level 1, level 2 and single engine level 3 airplanes. (2) Have means of egress (openings, exits or emergency exits), that can be readily located and opened from the inside and outside. The means of opening must be simple and obvious and marked inside and outside the airplane. (3) Have easy access to emergency exits when present.
		(b) Airplanes approved for aerobatics must have a means to egress the airplane in flight.

Subpart	Section	Note
	§23.2320 Occupant physical environment.	(a) The applicant must design the airplane to— (1) Allow clear communication between the flightcrew and passengers; (2) Protect the pilot and flight controls from propellers; and (3) Protect the occupants from serious injury due to damage to windshields, windows, and canopies.
		(b) For level 4 airplanes, each windshield and its supporting structure directly in front of the pilot must withstand, without penetration, the impact equivalent to a two-pound bird when the velocity of the airplane is equal to the airplane's maximum approach flap speed.
		(c) The airplane must provide each occupant with air at a breathable pressure, free of hazardous concentrations of gases, vapors, and smoke during normal operations and likely failures.
		(d) If a pressurization system is installed in the airplane, it must be designed to protect against— (1) Decompression to an unsafe level; and (2) Excessive differential pressure.
		(e) If an oxygen system is installed in the airplane, it must— (1) Effectively provide oxygen to each user to prevent the effects of hypoxia; and (2) Be free from hazards in itself, in its method of operation, and its effect upon other components.
Fire and High Energy Protection		
	§23.2325 Fire protection.	(a) The following materials must be self-extinguishing— (1) Insulation on electrical wire and electrical cable; (2) For levels 1, 2, and 3 airplanes, materials in the baggage and cargo compartments inaccessible in flight; and (3) For level 4 airplanes, materials in the cockpit, cabin, baggage, and cargo compartments.
		(b) The following materials must be flame resistant— (1) For levels 1, 2 and 3 airplanes, materials in each compartment accessible in flight; and (2) Any equipment associated with any electrical cable installation and that would overheat in the event of circuit overload or fault.
		(c) Thermal/acoustic materials in the fuselage, if installed, must not be a flame propagation hazard.
		(d) Sources of heat within each baggage and cargo compartment that are capable of igniting adjacent objects must be shielded and insulated to prevent such ignition.

Subpart	Section	Note
		(e) For level 4 airplanes, each baggage and cargo compartment must— (1) Be located where a fire would be visible to the pilots, or equipped with a fire detection system and warning system; and (2) Be accessible for the manual extinguishing of a fire, have a built-in fire extinguishing system, or be constructed and sealed to contain any fire within the compartment.
		(f) There must be a means to extinguish any fire in the cabin such that— (1) The pilot, while seated, can easily access the fire extinguishing means; and (2) For levels 3 and 4 airplanes, passengers have a fire extinguishing means available within the passenger compartment.
		(g) Each area where flammable fluids or vapors might escape by leakage of a fluid system must— (1) Be defined; and (2) Have a means to minimize the probability of fluid and vapor ignition, and the resultant hazard, if ignition occurs.
		(h) Combustion heater installations must be protected from uncontained fire.
	§23.2330 Fire protection in designated fire zones and adjacent areas.	(a) Flight controls, engine mounts, and other flight structures within or adjacent to designated fire zones must be capable of withstanding the effects of a fire.
		(b) Engines in a designated fire zone must remain attached to the airplane in the event of a fire.
		(c) In designated fire zones, terminals, equipment, and electrical cables used during emergency procedures must be fire-resistant.
	§23.2335 Lightning protection.	The airplane must be protected against catastrophic effects from lightning.

5.3.5. Review of Normal Category Airplanes, Subpart E, Powerplant

In Table 7, FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart E, Powerplant, is examined. And most of §§23.2400-23.24440 are applicable to electric propulsion essentially unchanged. There are some that require reconsideration. For example, § 23.2430, Fuel Systems, will require a focus on engine power management and distribution, rather than fuel system, and §23.2435, Powerplant induction and exhaust systems, should focus on the necessary electric propulsion air cooling and-or exhaust as necessary.

Table 7 - FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart E, Powerplant

Subpart	Section	Note
Subpart E—Powerplant		
	§23.2400 Powerplant installation.	(a)…the airplane powerplant installation must include each component necessary for propulsion, which affects propulsion safety, or provides auxiliary power to the airplane.
		(b) Each airplane engine and propeller must be type certificated, except for engines and propellers installed on level 1 low-speed airplanes, which may be approved under the airplane type certificate in accordance with a standard accepted by the FAA that contains airworthiness criteria … found appropriate and applicable to the specific design and intended use of the engine or propeller and provides a level of safety acceptable to the FAA.
		(c) The applicant must construct and arrange each powerplant installation to account for—(1) Likely operating conditions, including foreign object threats; ¶ (2) Sufficient clearance of moving parts to other airplane parts and their surroundings; ¶ (3) Likely hazards in operation including hazards to ground personnel; and ¶ (4) Vibration and fatigue.
		(d) Hazardous accumulations of fluids, vapors, or gases must be isolated from the airplane and personnel compartments, and be safely contained or discharged.
		(e) Powerplant components must comply with their component limitations and installation instructions or be shown not to create a hazard.
	§23.2405 Automatic power or thrust control systems.	(a) An automatic power or thrust control system intended for in-flight use must be designed so no unsafe condition will result during normal operation of the system.
		(b) Any single failure or likely combination of failures of an automatic power or thrust control system must not prevent continued safe flight and landing of the airplane.
		(c) Inadvertent operation of an automatic power or thrust control system by the flightcrew must be prevented, or if not prevented, must not result in an unsafe condition.
		(d) Unless the failure of an automatic power or thrust control system is extremely remote, the system must—(1) Provide a means for the flightcrew to verify the system is in an operating condition; ¶ (2) Provide a means for the flightcrew to override the automatic function; and ¶ (3) Prevent inadvertent deactivation of the system.

Subpart	Section	Note
	§23.2410 Powerplant installation hazard assessment.	… assess each powerplant separately and in relation to other airplane systems and installations to show that any hazard resulting from the likely failure of any powerplant system, component, or accessory will not—
		(a) Prevent continued safe flight and landing or, if continued safe flight and landing cannot be ensured, the hazard has been minimized;
		(b) Cause serious injury that may be avoided; and
		(c) Require immediate action by any crewmember for continued operation of any remaining powerplant system.
	§23.2415 Powerplant ice protection.	(a) The airplane design, including the induction and inlet system, must prevent foreseeable accumulation of ice or snow that adversely affects powerplant operation.
		(b) The powerplant installation design must prevent any accumulation of ice or snow that adversely affects powerplant operation, in those icing conditions for which certification is requested.
	§23.2420 Reversing systems.	Each reversing system must be designed so that—(a) No unsafe condition will result during normal operation of the system; and (b) The airplane is capable of continued safe flight and landing after any single failure, likely combination of failures, or malfunction of the reversing system.
	§23.2425 Powerplant operational characteristics.	(a) The installed powerplant must operate without any hazardous characteristics during normal and emergency operation within the range of operating limitations for the airplane and the engine.
		(b) The pilot must have the capability to stop the powerplant in flight and restart the powerplant within an established operational envelope.

Subpart	Section	Note
	§23.2430 Fuel systems.	(a) Each fuel system must—(1) Be designed and arranged to provide independence between multiple fuel storage and supply systems so that failure of any one component in one system will not result in loss of fuel storage or supply of another system; ¶ (2) Be designed and arranged to prevent ignition of the fuel within the system by direct lightning strikes or swept lightning strokes to areas where such occurrences are highly probable, or by corona or streamering at fuel vent outlets; ¶ (3) Provide the fuel necessary to ensure each powerplant and auxiliary power unit functions properly in all likely operating conditions; ¶ (4) Provide the flightcrew with a means to determine the total useable fuel available and provide uninterrupted supply of that fuel when the system is correctly operated, accounting for likely fuel fluctuations; ¶ (5) Provide a means to safely remove or isolate the fuel stored in the system from the airplane; ¶ (6) Be designed to retain fuel under all likely operating conditions and minimize hazards to the occupants during any survivable emergency landing. For level 4 airplanes, failure due to overload of the landing system must be taken into account; and ¶ (7) Prevent hazardous contamination of the fuel supplied to each powerplant and auxiliary power unit.
		(b) Each fuel storage system must—(1) Withstand the loads under likely operating conditions without failure; ¶ (2) Be isolated from personnel compartments and protected from hazards due to unintended temperature influences; ¶ (3) Be designed to prevent significant loss of stored fuel from any vent system due to fuel transfer between fuel storage or supply systems, or under likely operating conditions; ¶ (4) Provide fuel for at least one-half hour of operation at maximum continuous power or thrust; and ¶ (5) Be capable of jettisoning fuel safely if required for landing.
		(c) Each fuel storage refilling or recharging system must be designed to—(1) Prevent improper refilling or recharging; ¶ (2) Prevent contamination of the fuel stored during likely operating conditions; and ¶ (3) Prevent the occurrence of any hazard to the airplane or to persons during refilling or recharging.
	§23.2435 Powerplant induction and exhaust systems.	(a) The air induction system for each powerplant or auxiliary power unit and their accessories must—(1) Supply the air required by that powerplant or auxiliary power unit and its accessories under likely operating conditions; ¶ (2) Be designed to prevent likely hazards in the event of fire or backfire; ¶ (3) Minimize the ingestion of foreign matter; and ¶ (4) Provide an alternate intake if blockage of the primary intake is likely.
		(b) The exhaust system, including exhaust heat exchangers for each powerplant or auxiliary power unit, must—(1) Provide a means to safely discharge potential harmful material; and ¶ (2) Be designed to prevent likely hazards from heat, corrosion, or blockage.

Subpart	Section	Note
	§23.2440 Powerplant fire protection.	(a) A powerplant, auxiliary power unit, or combustion heater that includes a flammable fluid and an ignition source for that fluid must be installed in a designated fire zone.
		(b) Each designated fire zone must provide a means to isolate and mitigate hazards to the airplane in the event of fire or overheat within the zone.
		(c) Each component, line, fitting, and control subject to fire conditions must— ¶ (1) Be designed and located to prevent hazards resulting from a fire, including any located adjacent to a designated fire zone that may be affected by fire within that zone; ¶ (2) Be fire resistant if carrying flammable fluids, gas, or air or required to operate in event of a fire; and ¶ (3) Be fireproof or enclosed by a fire proof shield if storing concentrated flammable fluids.
		(d) The applicant must provide a means to prevent hazardous quantities of flammable fluids from flowing into, within or through each designated fire zone. This means must—(1) Not restrict flow or limit operation of any remaining powerplant or auxiliary power unit, or equipment necessary for safety; ¶ (2) Prevent inadvertent operation; and ¶ (3) Be located outside the fire zone unless an equal degree of safety is provided with a means inside the fire zone.
		(e) A means to ensure the prompt detection of fire must be provided for each designated fire zone—(1) On a multiengine airplane where detection will mitigate likely hazards to the airplane; or ¶ (2) That contains a fire extinguisher.
		(f) A means to extinguish fire within a fire zone, except a combustion heater fire zone, must be provided for—(1) Any fire zone located outside the pilot's view; ¶ (2) Any fire zone embedded within the fuselage, which must also include a redundant means to extinguish fire; and ¶ (3) Any fire zone on a level 4 airplane.

5.3.6. Review of Normal Category Airplanes, Subpart F, Equipment

Subpart F, Equipment, shown in Table 8, describes the subsystems to which the aircraft must conform. And while there is some reference to electrical systems, it is in the context of subsystems, not the electrical system supporting the propulsion system of the vehicle. However, there are some sections, in particular, §23.2515 Electrical and electronic system lightning protection; §23.2520 High-intensity Radiated Fields (HIRF) protection; and §23.2525 System power generation, storage, and distribution, which may have some useful methods to be applied to an electric propulsion system.

Table 8, FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart F, Equipment

Subpart	Section	Note
Subpart F—Equipment		
	§23.2500 Airplane level systems requirements.	This section applies generally to installed equipment and systems unless a section of this part imposes requirements for a specific piece of equipment, system, or systems.
		(a) The equipment and systems required for an airplane to operate safely in the kinds of operations for which certification is requested (Day VFR, Night VFR, IFR) must be designed and installed to— (1) Meet the level of safety applicable to the certification and performance level of the airplane; and (2) Perform their intended function throughout the operating and environmental limits for which the airplane is certificated.
		(b) The systems and equipment not covered by paragraph (a), considered separately and in relation to other systems, must be designed and installed so their operation does not have an adverse effect on the airplane or its occupants.
	§23.2505 Function and installation.	When installed, each item of equipment must function as intended.
	§23.2510 Equipment, systems, and installations.	For any airplane system or equipment whose failure or abnormal operation has not been specifically addressed by another requirement in this part, the applicant must design and install each system and equipment, such that there is a logical and acceptable inverse relationship between the average probability and the severity of failure conditions to the extent that:
		(a) Each catastrophic failure condition is extremely improbable;
		(b) Each hazardous failure condition is extremely remote; and
		(c) Each major failure condition is remote.
	§23.2515 Electrical and electronic system lightning protection.	An airplane approved for IFR operations must meet the following requirements, unless an applicant shows that exposure to lightning is unlikely:

Subpart	Section	Note
		(a) Each electrical or electronic system that performs a function, the failure of which would prevent the continued safe flight and landing of the airplane, must be designed and installed such that— (1) The function at the airplane level is not adversely affected during and after the time the airplane is exposed to lightning; and (2) The system recovers normal operation of that function in a timely manner after the airplane is exposed to lightning unless the system's recovery conflicts with other operational or functional requirements of the system.
		(b) Each electrical and electronic system that performs a function, the failure of which would significantly reduce the capability of the airplane or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed such that the system recovers normal operation of that function in a timely manner after the airplane is exposed to lightning.
	§23.2520 High-intensity Radiated Fields (HIRF) protection.	(a) Each electrical and electronic systems that perform a function, the failure of which would prevent the continued safe flight and landing of the airplane, must be designed and installed such that— (1) The function at the airplane level is not adversely affected during and after the time the airplane is exposed to the HIRF environment; and (2) The system recovers normal operation of that function in a timely manner after the airplane is exposed to the HIRF environment, unless the system's recovery conflicts with other operational or functional requirements of the system.
		(b) For airplanes approved for IFR operations, each electrical and electronic system that performs a function, the failure of which would significantly reduce the capability of the airplane or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed such that the system recovers normal operation of that function in a timely manner after the airplane is exposed to the HIRF environment.
	§23.2525 System power generation, storage, and distribution.	The power generation, storage, and distribution for any system must be designed and installed to—
		(a) Supply the power required for operation of connected loads during all intended operating conditions;
		(b) Ensure no single failure or malfunction of any one power supply, distribution system, or other utilization system will prevent the system from supplying the essential loads required for continued safe flight and landing; and

Subpart	Section	Note
		(c) Have enough capacity, if the primary source fails, to supply essential loads, including non-continuous essential loads for the time needed to complete the function required for continued safe flight and landing.
	§23.2530 External and cockpit lighting.	(a) The applicant must design and install all lights to minimize any adverse effects on the performance of flightcrew duties.
		(b) Any position and anti-collision lights, if required by part 91 of this chapter, must have the intensities, flash rate, colors, fields of coverage, and other characteristics to provide sufficient time for another aircraft to avoid a collision.
		(c) Any position lights, if required by part 91 of this chapter, must include a red light on the left side of the airplane, a green light on the right side of the airplane, spaced laterally as far apart as practicable, and a white light facing aft, located on an aft portion of the airplane or on the wing tips.
		(d) Any taxi and landing lights must be designed and installed so they provide sufficient light for night operations.
		(e) For seaplanes or amphibian airplanes, riding lights must provide a white light visible in clear atmospheric conditions.
	§23.2535 Safety equipment.	Safety and survival equipment, required by the operating rules of this chapter, must be reliable, readily accessible, easily identifiable, and clearly marked to identify its method of operation.
	§23.2540 Flight in icing conditions.	An applicant who requests certification for flight in icing conditions defined in part 1 of appendix C to part 25 of this chapter, or an applicant who requests certification for flight in these icing conditions and any additional atmospheric icing conditions, must show the following in the icing conditions for which certification is requested:
		(a) The ice protection system provides for safe operation.
		(b) The airplane design must provide protection from stalling when the autopilot is operating.
	§23.2545 Pressurized systems elements.	Pressurized systems must withstand appropriate proof and burst pressures.
	§23.2550 Equipment containing high-energy rotors.	Equipment containing high-energy rotors must be designed or installed to protect the occupants and airplane from uncontained fragments.

5.3.7. Review of Normal Category Airplanes, Subpart G, Flightcrew Interface and Other Information

Subpart G, Flightcrew Interface and Other Information, shown in Table 9, predominantly describes the flightcrew information to which the aircraft must conform. Of particular note, is §23.2615 Flight, navigation, and powerplant instruments, which describes the necessary powerplant instrumentation, and §23.2620 Airplane flight manual.

Table 9, FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart G, Flightcrew Interface and Other Information

Subpart	Section	Note
Subpart G—Flightcrew Interface and Other Information		
	§23.2600 Flightcrew interface.	(a) The pilot compartment, its equipment, and its arrangement to include pilot view, must allow each pilot to perform his or her duties, including taxi, takeoff, climb, cruise, descent, approach, landing, and perform any maneuvers within the operating envelope of the airplane, without excessive concentration, skill, alertness, or fatigue.
		(b) The applicant must install flight, navigation, surveillance, and powerplant controls and displays so qualified flightcrew can monitor and perform defined tasks associated with the intended functions of systems and equipment. The system and equipment design must minimize flightcrew errors, which could result in additional hazards.
		(c) For level 4 airplanes, the flightcrew interface design must allow for continued safe flight and landing after the loss of vision through any one of the windshield panels.
	§23.2605 Installation and operation.	(a) Each item of installed equipment related to the flightcrew interface must be labelled, if applicable, as to it identification, function, or operating limitations, or any combination of these factors.
		(b) There must be a discernible means of providing system operating parameters required to operate the airplane, including warnings, cautions, and normal indications to the responsible crewmember.
		(c) Information concerning an unsafe system operating condition must be provided in a timely manner to the crewmember responsible for taking corrective action. The information must be clear enough to avoid likely crewmember errors.
	§23.2610 Instrument markings, control markings, and placards.	(a) Each airplane must display in a conspicuous manner any placard and instrument marking necessary for operation.

Subpart	Section	Note
		(b) The design must clearly indicate the function of each cockpit control, other than primary flight controls.
		(c) The applicant must include instrument marking and placard information in the Airplane Flight Manual.
	§23.2615 Flight, navigation, and powerplant instruments.	(a) Installed systems must provide the flightcrew member who sets or monitors parameters for the flight, navigation, and powerplant, the information necessary to do so during each phase of flight. This information must— (1) Be presented in a manner that the crewmember can monitor the parameter and determine trends, as needed, to operate the airplane; and (2) Include limitations, unless the limitation cannot be exceeded in all intended operations.
		(b) Indication systems that integrate the display of flight or powerplant parameters to operate the airplane or are required by the operating rules of this chapter must— (1) Not inhibit the primary display of flight or powerplant parameters needed by any flightcrew member in any normal mode of operation; and (2) In combination with other systems, be designed and installed so information essential for continued safe flight and landing will be available to the flightcrew in a timely manner after any single failure or probable combination of failures.
	§23.2620 Airplane flight manual.	The applicant must provide an Airplane Flight Manual that must be delivered with each airplane.
		(a) The Airplane Flight Manual must contain the following information— (1) Airplane operating limitations; (2) Airplane operating procedures; (3) Performance information; (4) Loading information; and (5) Other information that is necessary for safe operation because of design, operating, or handling characteristics.
		(b) The following sections of the Airplane Flight Manual must be approved by the FAA in a manner specified by the administrator— (1) For low-speed, level 1 and 2 airplanes, those portions of the Airplane Flight Manual containing the information specified in paragraph (a)(1) of this section; and (2) For high-speed level 1 and 2 airplanes and all level 3 and 4 airplanes, those portions of the Airplane Flight Manual containing the information specified in paragraphs (a)(1) thru (a)(4) of this section.
Appendix A to Part 23—Instructions for Continued Airworthiness		

In summary, the other subparts to FAR 23, in addition to Subpart E, Powerplant, have relevant considerations for electric propulsion vehicles, but have no paragraphs that require revision to make them applicable to such vehicles.

6. Review of the Means of Compliance by Advisory Circulars

For each FAR section, a series of advisory circulars are used to describe acceptable, but not exclusive, means of compliance to the FARs.

6.1. FAR 23, Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

Table 10 shows the Advisory Circulars that support the means of compliance for Normal Category Airplanes.

Table 10 - Advisory Circulars Describing Means of Compliance for FAR 23

AC	Title	Purpose…
AC 23.2010-1	FAA Accepted Means of Compliance Process for 14 CFR Part 23	"…how to submit a proposed means of compliance to Title 14, Code of Federal Regulations (14 CFR) part 23 for acceptance by the Administrator in accordance with § 23.2010, Accepted means of compliance. This guidance provides information to applicants seeking approval for a type certificate (TC), an amended TC, a supplemental type certificate (STC), an amended STC, type design changes, or parts manufacturer approval (PMA) that require use of the airworthiness standards contained in part 23."
AC 23-15A	Small Airplane Certification Compliance Program	"…provides a compilation of historically acceptable means of compliance to specifically selected sections of 14 CFR part 23 that have become burdensome for small, simple, low performance airplanes (see Applicability section below) to show compliance. However, applicability of these means of compliance remains the responsibility of the certification manager for each specific project. Utilization of these means of compliance does not affect the applicability of any other certification requirements that fall outside the scope of this AC. This material is neither mandatory nor regulatory in nature and does not constitute a regulation." and CHG 1 "…revises existing material in two sentences."
AC 23-16A	Powerplant Guide for Certification of Part 23 Airplanes and Airships	"…provides information and guidance about acceptable means, but not the only means of compliance with Title 14 of the Code of Federal Regulations (14 CFR) part 23, subpart E, applicable to the powerplant installation in normal, utility, acrobatic, and commuter category airplanes. This AC consolidates existing policy documents, and certain AC's that cover specific paragraphs of the regulations, into a single document."
AC 23.1309-1E	System Safety Analysis and Assessment for Part 23 Airplanes	"…sets forth an acceptable means of showing compliance with Title 14 of the Code of Federal Regulations (14 CFR), § 23.1309, through Amendment 23-62: for equipment, systems, and installations in 14 CFR part 23 airplanes."

6.2. FAR 33, Airworthiness Standards: Aircraft Engines

Table 11 shows the Advisory Circulars that support the means of compliance for Aircraft Engines.

Table 11 - Advisory Circulars Describing Means of Compliance for FAR 33

AC	Title	Purpose…
AC 33-6	Weld Repair of Aluminum Crankcases and Cylinders of Piston Engines	"…provides guidelines for the development of repair procedures for weld repairs on crankcases and cylinders of piston engines."
AC 33.17-1A	Engine Fire Protection 33.17	"…provides definitions, guidance, and acceptable methods, but not the only methods, that may be used to demonstrate compliance with the engine fire protection requirements of Title 14 Code of Federal Regulations (14 CPR 33.17)."
AC 33.19-1	Guidance Material for 14 CFR §33.19, Durability, for Reciprocating Engine Redesigned Parts	"…provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate that redesigned parts for reciprocating engines comply with the requirements of §33.19 of Title 14 of the Code of Federal Regulations (14 CFR)."
AC 33.27-1A	Engine and Turbosupercharger Rotor Overspeed Requirements of 14 CFR § 33.27	"…provides guidance and acceptable methods, but not the only methods, for demonstrating compliance with the rotor strength (overspeed) requirements of Title 14 of the Code of Federal Regulations (14 CFR) 33.27."
AC 33.28-1	Compliance Criteria for 14 CFR §33.28, Aircraft Engines, Electrical and Electronic Engine Control Systems	"…provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate compliance with §33.28 of Title 14 of the Code of Federal Regulations (14 CFR 33.28), Electrical and electronic engine control systems."
AC 33.28-2	Guidance Material for 14 CFR 33.28, Reciprocating Engine, Electrical and Electronic Engine Control Systems	"…provides guidance and acceptable methods, but not the only methods, that may be used by designers of reciprocating engine electronic control systems to demonstrate compliance with §33.28 of Title 14 of the Code of Federal Regulations (14 CFR 33.28), Electrical and electronic engine control systems."
AC 33.28-3	Guidance Material For 14 CFR § 33.28, Engine Control Systems	"…provides guidance and describes acceptable methods, but not the only methods, for demonstrating compliance with the engine control systems requirements of § 33.28 of Title 14 of the Code of Federal Regulations (14 CFR part 33) at amendment level 33-26."
AC 33.47-1	Detonation Testing in Reciprocating Aircraft Engines	"…provides guidance material and information relating to detonation testing for reciprocating aircraft engines."

AC	Title	Purpose…
AC 33.75-1A	Guidance Material For 14 CFR 33.75, Safety Analysis	"…provides guidance and describes acceptable methods, but not the only methods, for demonstrating compliance with the safety analysis requirements of § 33.75 of Title 14 of the Code of Federal Regulations (14 CFR)."

6.3. Airworthiness Standards: Propellers

Table 12 shows the Advisory Circulars that support the means of compliance for Propellers.

Table 12 - Advisory Circulars Describing Means of Compliance for FAR 35

AC	Title	Purpose…
AC 35-1	Certification of Propellers	"…provides guidance and describes acceptable methods, but not the only methods, that may be used to demonstrate compliance with provisions of the requirements of part 35 of Title 14 of the Code of Federal Regulations (14 CFR part 35)."
AC 35.37-1B	Propeller Fatigue Limits and Evaluation	"…provides guidance and describes methods, but not the only methods, for demonstrating compliance with § 35.37, Propeller fatigue limits and evaluation, of Title 14 of the Code of Federal Regulations (14 CFR)."
AC 35.23-1	Guidance Material for 14 CFR § 35.23, Propeller Control System	"…provides definitions and guidance for demonstrating compliance with the propeller control system requirements of Title 14 of the Code of Federal Regulations (14 CFR 35.23)."
AC 35.16-1	Propeller Critical Parts	"…provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate compliance with the propeller critical parts requirements of Title 14 of the Code of Federal Regulations (14 CFR) § 35.16."
AC 20-143	Installation, Inspection, and Maintenance of Controls for General Aviation Reciprocating Aircraft Engines	"…presents information regarding the inspection, maintenance, and installation of engine controls with emphasis on the airframe portion of these systems. It provides guidance to design and maintenance personnel to reduce the number of airplane accidents and incidents related to the loss of engine power control."
AC 20-127	Use of Society of Automotive Engineers (SAE) Class H11 Bolts	"…provides guidance on the use of Society of Automotive Engineers {SAE) Class HII bolts in primary structure on all aircraft, including gliders and manned free balloons, and on aircraft engines and propellers."

7. Review of Means of Compliance by Standards

7.1. ASTM Standards

Through the establishment of a Part 23 Aviation Rulemaking Committee[9] (ARC), industry expressed an interest in evolving Part 23 regulations into a more performance-based document, reliant on standards for the design and performance of aircraft, in order to leverage all the benefits that referencing standards has to offer. Ultimately, the desire is to reduce the regulatory burden on the industry (and therefore the cost of the aircraft) and leverage standards to allow technology to be readily updated in a streamlined certification process where appropriate.

ASTM has established a number of committees to assist in the development of standards for general aviation aircraft.

Committee F39 on Aircraft Systems will develop standards related to the design, certification, production, installation, or maintenance of aircraft systems.

Committee F44 on General Aviation Aircraft addresses issues related to design and construction, systems and performance, quality acceptance tests, and safety monitoring for general aviation aircraft (covered under 14 CFR Part 23) that is less than 19,000 pounds and 12 passengers.

There are nine subcommittees: General (F44.10), Flight (F44.20), Structures (F44.30), Powerplant (F44.40), Systems and Equipment (F44.50), Executive (F44.90), Terminology (F44.91), Regulatory Liaisons (F44.92), and Industry Liaison (F44.93). Associated with the subcommittees, there are six key documents produced: Standard Terminology for Aircraft (F3060), Standard Specification for Control, Operational Characteristics and Installation of Instruments and Sensors of Propulsion Systems (F3064), Standard Specification for Flight for General Aviation Aeroplanes (F3082), Standard Specification for Design Loads and Conditions (F3116), Standard Specification for Crew Interface in Aircraft (F3117), and Standard Specification for Ice Protection for General Aviation Aircraft (F3120).

The General Committee (F44.10) has published Standard Specification for Normal Category Aeroplanes Certification[10] (Designation: F3264 − 18). The Standard reflects Federal Aviation Administration (FAA) Regulations 14 CFR 23, Amendment 64 Airworthiness Standards: Normal Category Airplanes Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401- 0001, http://www.access.gpo.gov; and the European Aviation Safety Agency (EASA) Regulations CS 23, Amendment 5 Certification Specifications for Normal Category Aeroplanes

[9] The charter for the "14 CFR Part 23 Reorganization Aviation Rulemaking Committee" is available at https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/Part23RARC-8152011.pdf

[10] This specification is under the jurisdiction of ASTM Committee F44 on General Aviation Aircraft and is the direct responsibility of Subcommittee F44.10 on General. Current edition approved March 1, 2018. Published March 2018. Originally approved in 2017. Last previous edition approved in 2017 as F3264 – 17. DOI: 10.1520/F3264-18.

Available from European Aviation Safety Agency (EASA), Postfach 10 12 53, D-50452 Cologne, Germany, www.easa.europa.eu. https://www.easa.europa.eu/document-library/certification-specifications/cs-23amendment-5. The Standard references the following ASTM standards:

- F2490 Guide for Aircraft Electrical Load and Power Source Capacity Analysis
- F3060 Terminology for Aircraft
- F3061/F3061M Specification for Systems and Equipment in Small Aircraft
- F3062/F3062M Specification for Aircraft Powerplant Installation
- F3063/F3063M Specification for Aircraft Fuel and Energy Storage and Delivery
- F3064/F3064M Specification for Aircraft Powerplant Control, Operation, and Indication F3065/F3065M Specification for Aircraft Propeller System Installation
- F3066/F3066M Specification for Aircraft Powerplant Installation Hazard Mitigation F3082/F3082M Specification for Weights and Centers of Gravity of Aircraft
- F3083/F3083M Specification for Emergency Conditions, Occupant Safety and Accommodations F3093/F3093M Specification for Aeroelasticity Requirements
- F3114 Specification for Structures
- F3115/F3115M Specification for Structural Durability for Small Airplanes
- F3116/F3116M Specification for Design Loads and Conditions
- F3117 Specification for Crew Interface in Aircraft
- F3120/F3120M Specification for Ice Protection for General Aviation Aircraft
- F3173/F3173M Specification for Aircraft Handling Characteristics
- F3174/F3174M Specification for Establishing Operating Limitations and Information for Aeroplanes F3179/F3179M Specification for Performance of Aeroplanes
- F3180/F3180M Specification for Low-Speed Flight Characteristics of Aircraft
- F3227/F3227M Specification for Environmental Systems in Small Aircraft
- F3228 Specification for Flight Data and Voice Recording in Small Aircraft
- F3229/F3229M Practice for Static Pressure System Tests in Small Aircraft
- F3230 Practice for Safety Assessment of Systems and Equipment in Small Aircraft
- F3231/F3231M Specification for Electrical Systems in Small Aircraft
- F3232/F3232M Specification for Flight Controls in Small Aircraft
- F3233/F3233M Specification for Instrumentation in Small Aircraft
- F3234/F3234M Specification for Exterior Lighting in Small Aircraft
- F3235 Specification for Aircraft Storage Batteries
- F3236 Specification for High Intensity Radiated Field (HIRF) Protection in Small Aircraft

The Powerplant subcommittee (F44.40) has five active Standard Specifications for: Aircraft Powerplant Installation (F3062/F3062M-18), Aircraft Fuel and Energy Storage and Delivery (F3063/F3063M-18), Aircraft Powerplant Control, Operation, and Indication (F3064/F3064M-18a), Aircraft Propeller System Installation (F3065/F3065M-18), and Aircraft Powerplant Installation Hazard Mitigation (F3066/F3066M-18). And there are four proposed new standards in Aircraft Electric Propulsion Systems (WK41136), New Specification for Control, Operational Characteristics, and Installation of Instruments and Sensor of Propulsion Systems Installed on Small Airplanes (WK46999), New Specification for Installation and Integration of Propeller Systems for Small Airplanes (WK47000), and Guide for Powerplant Instruments (WK62786).

The Powerplant subcommittee (F44.40) published the Standard Specification for Aircraft Powerplant Installation[11] (ASTM F3062 / F3062M - 18). This Standard references 14 CFR part 33 Airworthiness Standards: Aircraft Engines and 14 CFR part 35 Airworthiness Standards: Propellers; Joint Aviation Authorities (JAA) Joint Airworthiness Requirements (JAR) JAR-E and JAR-P Propellers; and FAA AC 23-8C Flight Test Guide for certification of part 23 airplanes, CAR 13 Aircraft Engines Airworthiness, and TSO C77 Technical Standard Order Gas Turbine Auxiliary Power Units. The Standard references the following ASTM standards:

- F2339 Practice for Design and Manufacture of Reciprocating Spark Ignition Engines for Light Sport Aircraft
- F2506 Specification for Design and Testing of Light Sport Aircraft Propellers
- F2538 Practice for Design and Manufacture of Reciprocating Compression Ignition Engines for Light Sport Aircraft
- F2840 Practice for Design and Manufacture of Electric Propulsion Units for Light Sport Aircraft F3060 Terminology for Aircraft
- F3063/F3063M Specification for Aircraft Fuel and Energy Storage and Delivery F3066/F3066M Specification for Aircraft Powerplant Installation Hazard Mitigation
- F3117 Specification for Crew Interface in Aircraft

The Powerplant subcommittee (F44.40) published the Standard Specification for Aircraft Propeller System Installation (ASTM F3065 / F3065M - 18). This Standard references only ASTM Standard F3060 Terminology for Aircraft.

[11] This specification is under the jurisdiction of ASTM Committee F44 on General Aviation Aircraft and is the direct responsibility of Subcommittee F44.40 on Powerplant. Current edition approved Jan. 1, 2018. Published February 2018. Originally approved in 2015. Last previous edition approved in 2016 as F3062/F3062M – 16. DOI: 10.1520/F3062_F3062M-18.

The Powerplant subcommittee (F44.40) published the Standard Specification for Aircraft Fuel and Energy Storage and Delivery (ASTM F3063 / F3063M - 18a). This Standard references the following ASTM Standards:

- F3060 Terminology for Aircraft
- F3116/F3116M Specification for Design Loads and Conditions
- F3117 Specification for Crew Interface in Aircraft
- F3179/F3179M Specification for Performance of Aircraft

The Powerplant subcommittee (F44.40) published the Standard Specification for Aircraft Powerplant Control, Operation, and Indication (ASTM F3064 / F3064M - 18a). This Standard references 14 CFR Part 23 Amendment 62, and the following ASTM Standards:

- F3060 Terminology for Aircraft
- F3062/F3062M Specification for Installation of Powerplant Systems
- F3063/F3063M Specification for Aircraft Fuel and Energy Storage and Delivery
- F3066/F3066M Specification for Aircraft Powerplant Installation Hazard Mitigation
- F3116/F3116M Specification for Design Loads and Conditions
- F3117 Specification for Crew Interface in Aircraft

The Powerplant subcommittee (F44.40) published the Standard Specification for Aircraft Powerplant Installation Hazard Mitigation (ASTM F3066 / F3066M - 18). This Standard references 14 CFR Part 23, and the following ASTM Standards:

- F3060 Terminology for Aircraft
- F3061/F3061M Specification for Systems and Equipment in Small Aircraft
- F3062/F3062M Specification for Aircraft Powerplant Installation
- F3114 Specification for Structures
- F3116/F3116M Specification for Design Loads and Conditions
- F3120/F3120M Specification for Ice Protection for General Aviation Aircraft

7.2. FAA Notice of Availability of MOC Based on ASTM Standards in Committee F44

The FAA published an "Accepted Means of Compliance; Airworthiness Standards: Normal Category Airplanes" in the Federal Register[12]. In this Notice of Availability (NOA), the FAA announced the availability of 63 Means of Compliance (MOC) based on 30 published ASTM International (ASTM) consensus standards developed by ASTM Committee F44 on General Aviation Aircraft (see the previous section in this report). A total of 46 of these accepted MOCs consist of ASTM consensus standards as published, with the remaining 17 MOCs comprised of a combination of ASTM standards and FAA changes. The FAA finds these MOCs to be an acceptable means, but not the only means, of showing compliance to the applicable regulations in part 23, amendment 23-64, for normal category airplanes. Through the NOA, the FAA invited comments by the public. As of this report, the final notice has not been published.

Table 13 is the list of all of the Means of Compliance organized by the subpart and sections within FAR 23.

Table 13, FAA List of Sections from Part 23, Amendment 23-64, Followed by Their Corresponding MOC

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.1457	ASTM F3264-17, section 9.12		
	FAR 23.1459	ASTM F3264-17, section 9.13		
	FAR 23.1529	ASTM F3264-17, section 10.6		
Subpart B—Flight				
	FAR 23.2100	ASTM F3264-17, section 5.1		
	FAR 23.2105	ASTM F3264-17, section 5.2		
	FAR 23.2110	ASTM F3264-17, section 5.3		
	FAR 23.2115	ASTM F3264-17, section 5.4		
	FAR 23.2120	ASTM F3264-17, section 5.5		

[12] "Accepted Means of Compliance; Airworthiness Standards: Normal Category Airplanes, A Rule by the Federal Aviation Administration on 05/11/2018" available at https://www.federalregister.gov/documents/2018/05/11/2018-09990/accepted-means-of-compliance-airworthiness-standards-normal-category-airplanes

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.2125	ASTM F3264-17, section 5.6		
	FAR 23.2130	ASTM F3264-17, section 5.7		
	FAR 23.2135	ASTM F3264-17, section 5.8, combined with the changes in the following table:	ASTM F3173/F3173M-17, Sections 4.9.1.1 and 4.9.1.2	FAA 4.9.1.1 and 4.9.1.2: 4.9.1.1: “For a level 1 or 2 airplane, or level 3 or 4 airplane of 6,000 pounds or less maximum weight, 5 seconds from initiation of roll and”
				4.9.1.2: “For a level 3 or 4 airplane of over 6,000 pounds maximum weight, (W+500)/1300 seconds, but not more than 10 seconds, where W is the weight in pounds.”
			ASTM F3173/F3173M-17, Sections 4.9.3.1 and 4.9.3.2	FAA 4.9.3.1 and 4.9.3.2: 4.9.3.1: “For a level 1 or 2 airplane, or level 3 or 4 airplane of 6,000 pounds or less maximum weight, 4 seconds from initiation of roll and”
				4.9.3.2: “For a level 3 or 4 airplane of over 6,000 pounds maximum weight, (W+2,800)/2,200 seconds, but not more than 7 seconds, where W is the weight in pounds.”
	FAR 23.2140	ASTM F3264-17, section 5.9		
	FAR 23.2145	ASTM F3264-17, section 5.10		
	FAR 23.2150	ASTM F3264-17, section 5.11		

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.2155	ASTM F3264-17, section 5.12		
	FAR 23.2160	ASTM F3264-17, section 5.13		
	FAR 23.2165	ASTM F3264-17, section 5.14		
Subpart C—Structures				
	FAR 23.2200	ASTM F3264-17, Section 6.1, combined with the changes in the following table:	ASTM F3116/F3116M-15, Section 4.1.4	FAA 4.1.4: "Appendix X1 through appendix X4 provide, within the limitations specified within the appendix, a simplified means of compliance with several of the requirements set forth in 4.2 to 4.26 and 7.1 to 7.9 that can be applied as one (but not the only) means to comply. If the simplified methods in appendix X1 through appendix X3 are used, they must be used together in their entirety."
			ASTM F3116/F3116M-15, Section 4.10.1.1	FAA 4.10.1.1: "In condition A, assume 100% of the semispan wing airload acts on one side of the airplane and 75% of this load acts on the other side. For airplanes with maximum weight of 1,000 pounds or less, 70% of the load acts on the other side."
			ASTM F3116/F3116M-15, Section X1.1.1	FAA X1.1.1: "The methods provided in this appendix provide one possible means (but not the only possible means) of compliance and can only be applied to low-speed, level 1 and level 2 airplanes."

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
			ASTM F3116/F3116M-15, Section X1.1.4	X1.1.4 through X1.1.4.5: Same as published in F3116/F3116M-15. Add FAA X1.1.4.6: "Wings with winglets, tip tanks, or tip fins."
	FAR 23.2220	ASTM F3264-17, section 6.5		
	FAR 23.2225	ASTM F3264-17, section 6.6, combined with the changes in the following table:	ASTM F3116/F3116M-15, Section X2.1.1	FAA X2.1.1: "The methods provided in this appendix provide one possible means (but not the only possible means) of compliance and can only be applied to low-speed, level 1 and level 2 airplanes."
			ASTM F3116/F3116M-15, Section X3.1.1	FAA X3.1.1: "The methods provided in this appendix provide one possible means (but not the only possible means) of compliance and can only be applied to low-speed, level 1 and level 2 airplanes."
			ASTM F3116/F3116M-15, Section X4.1.1	FAA X4.1.1: "The methods provided in this appendix provide one possible means (but not the only possible means) of compliance and can only be applied to low-speed, level 1 airplanes."
	FAR 23.2230	ASTM F3264-17, section 6.7		
	FAR 23.2235	ASTM F3264-17, section 6.8, combined with the changes in the following table:	ASTM F3264-17, Section 6.8.1	FAA 6.8.1: "F3114-15 Standard Specification for Structures".

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.2240	ASTM F3264-17, section 6.9, combined with the changes in the following table:	ASTM F3115/F3115M-15, Section 4.4.1	FAA 4.4.1: "For metallic (aluminum), unpressurized, non-aerobatic, low-speed, level 1 airplanes, applicants can demonstrate a 10,000 hour safe-life by limiting the '1g' gross stress, at maximum takeoff weight, to no more than 5.5 ksi. The applicant must show effective stress concentration factors of 4 or less in highly loaded joints and use materials or material systems for which the physical and mechanical properties are well established."
			ASTM F3115/F3115M-15, Section 6.1	FAA 6.1: "For bonded airframe structure, the residual strength of bonded joints shall be addressed as follows: For any bonded joint, the failure of which would result in catastrophic loss of the airplane, the limit load capacity must be substantiated by one of the following methods."
	FAR 23.2245	ASTM F3264-17, section 6.10		
	FAR 23.2250	ASTM F3264-17, section 6.11		
	FAR 23.2255	ASTM F3264-17, section 6.12		
	FAR 23.2260	ASTM F3264-17, section 6.13		
	FAR 23.2265	ASTM F3264-17, section 6.14		

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.2270	ASTM F3264-17, section 6.15		
Subpart D—Design and Construction				
	FAR 23.2300	ASTM F3264-17, section 7.1, combined with the changes in the following table:	ASTM F3232/F3232M-17, Table 1, Row 4.4.6	FAA Table 1, Row 4.4.6: A white circle ("o") in the following Aircraft Type Code (ATC) character fields: "Airworthiness Level—1" and "Stall Speed—L"; a mark-out ("x") in the following ATC character field: "Number of Engines—M"; and no codes in any other ATC character field.
				Note: This change applies the standard of ASTM F3232/F3232M-17, Section 4.4.6, to all single-engine airplanes except level 1 airplanes with a stall speed of 45 knots or less.
	FAR 23.2305	ASTM F3264-17, section 7.2		
	FAR 23.2315	ASTM F3264-17, section 7.4		
	FAR 23.2320	ASTM F3264-17, section 7.5		
	FAR 23.2325	ASTM F3264-17, section 7.6, combined with the changes in the following table:	ASTM F3061/F3061M-17, Section 10.3.2	FAA 10.3.2: "In each area where flammable fluids or vapors might escape by leakage of a fluid system, there must be means to minimize the probability of ignition of the fluids and vapors, and the resultant hazard if ignition does occur. These means must account for the factors prescribed in 10.3.3 through 10.3.7."

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.2330	ASTM F3264-17, section 7.7		
	FAR 23.2335	ASTM F3264-17, section 7.8		
Subpart E—Powerplant				
	FAR 23.2400	ASTM F3264-17, section 8.1, combined with the changes in the following table:	ASTM F3065/F3065M-15, Section 4.3	An FAA-accepted means of compliance for § 23.2400(c), such as the provisions of § 23.905(d), amendment 23-59.
	FAR 23.2405	ASTM F3264-17, section 8.2		
	FAR 23.2410	ASTM F3264-17, section 8.3, combined with the changes in the following table:	ASTM F3264-17, Section 8.3	8.3 through 8.3.2: Same as published in F3264-17. Renumber 8.3.3 to 8.3.6.
				Add FAA 8.3.3 through 8.3.5, and FAA 8.3.7: 8.3.3: "F3063/F3063M—16a Standard Specification for Design and Integration of Fuel/Energy Storage and Delivery System Installations for Aeroplanes".
				8.3.4: "F3064/F3064M—15 Standard Specification for Control, Operational Characteristics and Installation of Instruments and Sensors of Propulsion Systems".
				8.3.5: "F3065/F3065M—15 Standard Specification for Installation and Integration of Propeller System".

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.2415	ASTM F3264-17, section 8.4, combined with the changes in the following table:	ASTM F3264-17, Section 8.4	8.4 through 8.4.1: Same as published in F3264-17. Renumber 8.4.2 to 8.4.3.
				Add FAA 8.4.2: F3063/F3063M—"16a Standard Specification for Design and Integration of Fuel/Energy Storage and Delivery System Installations for Aeroplanes".
			ASTM F3066/F3066M-15, Section 5.1	An FAA-accepted means of compliance for the induction system ice protection aspects of § 23.2415, such as the provisions of § 23.1093(a), amendment 23-51.
			ASTM F3066/F3066M-15, Section 5.2.1.1	FAA 5.2.1.1: "Operate throughout its flight power range, including minimum descent idle speeds, in the icing and snow conditions specified in Specification F3120/F3120M, without the accumulation of ice on engine, inlet system components, or airframe components that would do any of the following:"
			ASTM F3066/F3066M-15, Section 5.2.2	[Remove]

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
			ASTM F3066/F3066M-15, Sections 5.2.3, 5.2.3.1, and 5.2.3.2	FAA 5.2.2: "Each turbine engine must idle for 30 min on the ground, with the air bleed available for engine icing protection at its critical condition, without adverse effect, in the ground icing conditions specified in Specification F3120/F3120M."
				FAA 5.2.2.1 Followed by momentary operation at takeoff power or thrust.
				FAA 5.2.2.2 During the 30 min of idle operation, the engine may be run up periodically to a moderate power or thrust setting."
	FAR 23.2420	ASTM F3264-17, section 8.5, combined with the changes in the following table:	ASTM F3264-17, Section 8.5	8.5 through 8.5.1: Same as published in F3264-17. Remove 8.5.2 and 8.5.3. Add FAA 8.5.2: F3065/F3065M—"15 Standard Specification for Installation and Integration of Propeller System".
	FAR 23.2405	ASTM F3264-17, section 8.2		
	FAR 23.2410	ASTM F3264-17, section 8.3, combined with the changes in the following table:	ASTM F3264-17, Section 8.3	8.3 through 8.3.2: Same as published in F3264-17. Renumber 8.3.3 to 8.3.6.
				Add FAA 8.3.3 through 8.3.5, and FAA 8.3.7: 8.3.3: "F3063/F3063M—16a Standard Specification for Design and Integration of Fuel/Energy Storage and Delivery System Installations for Aeroplanes".

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
				8.3.4: “F3064/F3064M—15 Standard Specification for Control, Operational Characteristics and Installation of Instruments and Sensors of Propulsion Systems”.
				8.3.5: “F3065/F3065M—15 Standard Specification for Installation and Integration of Propeller System”.
				8.3.7: “F3117—15 Standard Specification for Crew Interface in Aircraft”.
	FAR 23.2415	ASTM F3264-17, section 8.4, combined with the changes in the following table:	ASTM F3264-17, Section 8.4	8.4 through 8.4.1: Same as published in F3264-17. Renumber 8.4.2 to 8.4.3.
				Add FAA 8.4.2: F3063/F3063M—“16a Standard Specification for Design and Integration of Fuel/Energy Storage and Delivery System Installations for Aeroplanes”.
			ASTM F3066/F3066M-15, Section 5.1	An FAA-accepted means of compliance for the induction system ice protection aspects of § 23.2415, such as the provisions of § 23.1093(a), amendment 23-51.

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
			ASTM F3066/F3066M-15, Section 5.2.1.1	FAA 5.2.1.1: "Operate throughout its flight power range, including minimum descent idle speeds, in the icing and snow conditions specified in Specification F3120/F3120M, without the accumulation of ice on engine, inlet system components, or airframe components that would do any of the following:"
			ASTM F3066/F3066M-15, Section 5.2.2	[Remove]
			ASTM F3066/F3066M-15, Sections 5.2.3, 5.2.3.1, and 5.2.3.2	FAA 5.2.2: "Each turbine engine must idle for 30 min on the ground, with the air bleed available for engine icing protection at its critical condition, without adverse effect, in the ground icing conditions specified in Specification F3120/F3120M."
				FAA 5.2.2.1 Followed by momentary operation at takeoff power or thrust.
				FAA 5.2.2.2 During the 30 min of idle operation, the engine may be run up periodically to a moderate power or thrust setting."
	FAR 23.2420	ASTM F3264-17, section 8.5, combined with the changes in the following table:	ASTM F3264-17, Section 8.6	8.6 through 8.6.2: Same as published in F3264-17. Renumber 8.6.3 to 8.6.4.
				Add FAA 8.6.3 and FAA 8.6.5:

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
				8.6.3: “F3065/F3065M—15 Standard Specification for Installation and Integration of Propeller System”.
				8.6.5: “F3117—15 Standard Specification for Crew Interface in Aircraft”.
	FAR 23.2430	ASTM F3264-17, section 8.7, combined with the changes in the following table:	ASTM F3264-17, Section 8.7	8.7.1 through 8.7.5: Same as published in F3264-17.
				Add an FAA-accepted means of compliance for the fuel supply aspects of § 23.2430, such as the provisions of § 23.991(b), amendment 23-43.
			ASTM F3066/F3066M-15, Section 6.3	An FAA-accepted means of compliance for the fuel/oil tank aspects of § 23.2430, such as the provisions of § 23.967(d), amendment 23-43.
	FAR 23.2435	ASTM F3264-17, section 8.8		
	FAR 23.2440	ASTM F3264-17, section 8.9, combined with the changes in the following table:	ASTM Section 8.9, F3264-17	8.9 through 8.9.2: Same as published in F3264-17. Renumber 8.9.3 to 8.9.4.
				Renumber 8.9.4 to 8.9.5 and change to, “F3066/F3066M-15 Standard Specification for Powerplant Systems Specific Hazard Mitigation.”
				Add FAA 8.9.3:

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
				8.9.3: “F3063/F3063M-16a Standard Specification for Design and Integration of Fuel/Energy Storage and Delivery System Installations for Aeroplanes.”
Subpart F—Equipment				
	FAR 23.2500	ASTM F3264-17, section 9.1		
	FAR 23.2505	ASTM F3264-17, section 9.2		
	FAR 23.2510	ASTM F3264-17, section 9.3		
	FAR 23.2515	ASTM F3264-17, section 9.4		
	FAR 23.2520	ASTM F3264-17, section 9.5		
	FAR 23.2525	ASTM F3264-17, section 9.6		
	FAR 23.2530	ASTM F3264-17, section 9.7		
	FAR 23.2535	ASTM F3264-17, section 9.8		
	FAR 23.2540	ASTM F3264-17, section 9.9		
	FAR 23.2545	ASTM F3264-17, section 9.10		
	FAR 23.2550	ASTM F3061/F3061M-17, section 10.9		
Subpart G—Flightcrew Interface and Other Information				

Subpart	FAR §	ASTM F44 Document	FAA replace…	…with…
	FAR 23.2600	ASTM F3264-17, section 10.1, combined with the changes in the following table:	ASTM Section 10.1, F3264-17	10.1.1 through 10.1.5: Same as published in F3264-17. Add an FAA-accepted means of compliance for the windshield luminous transmittance aspects of § 23.2600, such as the provisions of § 23.775(e), amendment 23-49.
				Add an FAA-accepted means of compliance for the pilot compartment view with formation of fog or frost aspects of § 23.2600, such as the provisions of § 23.773(b), amendment 23-45.
	FAR 23.2605	ASTM F3264-17, section 10.2		
	FAR 23.2610	ASTM F3264-17, section 10.3		
	FAR 23.2615	ASTM F3264-17, section 10.4, combined with the changes in the following table:	ASTM Section 6, F3064/F3064M-15	An FAA-accepted means of compliance for the powerplant instruments aspects of § 23.2615, such as the provisions of § 23.1305, amendment 23-52.
	FAR 23.2620	ASTM F3264-17, sections 5.15 and 10.5		

7.3. RTCA Standards

RTCA Special Committees leverage the expertise of the aviation community to generate recommendations. RTCA works with the Federal Aviation Administration (FAA) to develop comprehensive, industry-vetted and endorsed standards that can be used as means of compliance with FAA regulations.

Special Committees develop Safety Performance Requirements (SPR), Operational Services and Environment Definitions (OSED), Interoperability Requirements (INTEROP), Minimum Aviation System

Performance Standards (MASPS), Minimum Operational Performance Standards (MOPS), reports and guidelines. These documents shape the certification of the safety and efficiency of new equipment and provide a competitive market for the implementation of these technologies. MASPS and MOPS are frequently referred to by the FAA in Technical Standard Orders and Advisory Circulars and, thereby, provide a partial basis for the certification of equipment. RTCA documents are also used by the private sector for development, investment and other business decisions.

MASPS specify characteristics that are useful to designers, installers, manufacturers, service providers and users of systems intended for operational use within a defined airspace. Where the systems are global in nature, international applications are taken in to consideration (often working with European Organisation for Civil Aviation Equipment [EUROCAE] and-or International Civil Aviation Organization [ICAO]). MASPS describe the system (subsystems / functions) and provide information needed to understand the rationale for system characteristics, operational goals, requirements and typical applications. Definitions and assumptions essential to proper understanding of MASPS are provided as well as minimum system test procedures to verify system performance compliance (e.g., end-to-end performance verification).

Compliance with RTCA MASPS is recommended as one means of assuring that the system and each subsystem will perform its intended function(s) satisfactorily under conditions normally encountered in routine aeronautical operations for the environments intended. MASPS may be implemented in part or in total.

MOPS provide standards for specific equipment(s) useful to designers, manufacturers, installers and users of the equipment. The word "equipment" used in MOPS includes all components and units necessary for the system to properly perform its intended function. MOPS provide the information needed to understand the rationale for equipment characteristics and requirements stated, describe typical equipment applications and operational goals, and establish the basis for required performance under the standard. Definitions and assumptions essential to proper understanding are provided as well as installed equipment tests and operational performance characteristics for equipment installations.

Compliance with RTCA MOPS is recommended as one means of assuring the equipment will perform its intended function(s) satisfactorily under all conditions normally encountered in routine aeronautical operations. MOPS may be implemented by one or more regulatory documents and-or advisory documents and may be implemented in part or in total.

7.4. SAE

SAE maintains publication collections, such as the Power and Propulsion Annual Subscription, which is a collection of technical papers, books, videos, magazines, white papers, and TechInsights all related to Power and Propulsion areas of interest for aerospace professionals. The technical content in the Power and Propulsion Annual Subscription provides information on current power and propulsion engineering practices and advancements such as electric aircraft and renewable fuels.

8. An Approach to Identify Areas to Focus Electric Propulsion Certification

In section 4, Technical Approach, a proposed method was to review each of the sections of the FAR, down to the paragraph, and assess whether that piece of regulation was unchanged, would need tailoring to be in line with the new technology, in this case electric propulsion, or whether it required to be revised to ensure relevance to the new technology. In Figure 3, the implication of the assessment is, for tailoring, whether the new technology informs the criteria for an applicable regulation, but leaves the regulation essentially unchanged in its meaning, and for revised, it means that both the condition and the criteria associated with a regulation are informed by the new technology.

The following tables examine the applicability and relevance of each of the sections under parts 35, 33 and 23 to electric propulsion and describe whether each section is unchanged (U), tailored (T) or requires revisions (R).

8.1. Review of the Airworthiness Standards: Propellers to Electric Propulsion

Table 14 shows the applicability of FAR 35, Airworthiness Standards: Propellers, to electric propulsion. There are two sections, §§35.39 and 35.40, which should be tailored. And that tailoring is associated with the changes that will be necessary in §33.49 (see Table 11), otherwise the rest of FAR 35 is applicable unchanged.

Table 14 - Applicability of FAR 35 to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart A—General		
	§35.1 Applicability.	U
	§35.2 Propeller configuration.	U
	§35.3 Instructions for propeller installation and operation.	U
	§35.4 Instructions for Continued Airworthiness.	U
	§35.5 Propeller ratings and operating limitations.	U
	§35.7 Features and characteristics.	U
Subpart B—Design and Construction		
	§35.15 Safety analysis.	U
	§35.16 Propeller critical parts.	U

Subpart	Section	Applicable: Unchanged, Tailored, Revised
	§35.17 Materials and manufacturing methods.	U
	§35.19 Durability.	U
	§35.21 Variable and reversible pitch propellers.	U
	§35.22 Feathering propellers.	U
	§35.23 Propeller control system.	U
	§35.24 Strength.	U
Subpart C—Tests and Inspections		
	§35.33 General.	U
	§35.34 Inspections, adjustments and repairs.	U
	§35.35 Centrifugal load tests.	U
	§35.36 Bird impact.	U
	§35.37 Fatigue limits and evaluation.	U
	§35.38 Lightning strike.	U
	§35.39 Endurance test.	T - see §33.49
	§35.40 Functional test.	T - see §35.39
	§35.41 Overspeed and overtorque.	U
	§35.42 Components of the propeller control system.	U
	§35.43 Propeller hydraulic components.	U
(Appendix A to Part 35—Instructions for Continued Airworthiness)		

8.2. Airworthiness Standards: Aircraft Engines

Table 15 shows the applicability of FAR 33, Airworthiness Standards: Aircraft Engines, to electric propulsion. While a number of the sections are applicable unchanged, there are seven of the 32 sections that require revision.

The first is in the General Subpart and is §33.7 Engine ratings and operating limitations, which requires revision of paragraph (b) "…ratings and operating limitations …[for]… reciprocating engines…" to address:

a. Horsepower (or torque), RPM, manifold pressure (not applicable for electric propulsion systems), and time at critical pressure altitude and sea level for both rated max power and rated takeoff power.
b. The equivalent replacement for "fuel grade or specification."
c. Lubrication.
d. Temperatures of cylinder (not applicable — is there an equivalent?), oil at the oil inlet (is this appropriate, or is there an equivalent?), and turbocharger turbine wheel inlet gas (not applicable).
e. Pressure of fuel (not applicable) and oil at the main oil gallery (what's the equivalent?).
f. Accessory drive torque and overhang moment.
g. Component Life.
h. Turbosupercharger turbine wheel RPM (not applicable).
i. Are there other ratings an operating limitations for electric propulsion systems?

The next is in Subpart B, Design and Construction and is §33.27 Turbine, compressor, fan, and turbosupercharger rotor overspeed, which may have little applicability for electric propulsion. However, there is significant discussion about overspeed conditions and the effects on shaft and its failure modes. These considerations should be evaluated for their safety implications within the electric propulsion system.

Subpart C, Design and Construction; Reciprocating Aircraft Engines, has three sections that require revision: §33.34 Turbocharger rotors, §33.35 Fuel and induction system, and §33.37 Ignition system. Turbocharge rotors is not applicable to electric propulsion design and construction. The fuel and induction system should be revised to ensure applicability to electric propulsion design and construction. And while the focus of §33.37, Ignition system, is on spark ignition, the equivalent design and construction objectives for electric propulsion should be addressed.

Finally, in Subpart D, Block Tests; Reciprocating Aircraft Engines, there are two sections that must be examined and revised.

The first is §33.47 Detonation test, which is a block test unique to reciprocating engines that is a fundamental engine failure mode due to engine knocking[13], and while knocking is an unsafe condition

[13] Engine knocking is a condition where combustion within a cylinder in an internal combustion engine does not occur as designed. The effect of knocking can be inconsequential, however if it continues it can be catastrophic to the engine structure.

particular to reciprocating engines, an testing for an equivalent unsafe condition for electric propulsion system would be worth identifying.

The second is §33.49 Endurance test. This test is an extensive evaluation of the engine during a grueling 150-hour series of tests at high power conditions. There are typically seven test conditions to meet the 150-hour test, which depending on the type of reciprocating engine can range from six (helicopter) to ten (gear-driven, two-speed superchargers) conditions. Revising the General paragraph is critical to ensure the relevance of the endurance test to electric propulsion systems, as the conditions are based on reciprocating engine parameters. This is the most critical revision to the Federal Aviation Regulations for electric propulsion.

There are three sections that should be tailored for electric propulsion: §33.17 Fire protection, §33.51 Operation test and §33.53 Engine system and component tests.

The fire protection section under Subpart B, Design and Construction, should be tailored to be applicable to electric propulsion.

The operation test and engine system and component tests under Subpart D, Block Tests, follow from the Endurance Test revisions.

Table 15 - Applicability of FAR 33 to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart A—General		
	§33.1 Applicability.	U
	§33.3 General.	U
	§33.4 Instructions for Continued Airworthiness.	U
	§33.5 Instruction manual for installing and operating the engine.	U
	§33.7 Engine ratings and operating limitations.	R - make §33.7(b) applicable to Electric Prop
	§33.8 Selection of engine power and thrust ratings.	U
Subpart B—Design and Construction		
	§33.11 Applicability.	U

Subpart	Section	Applicable: Unchanged, Tailored, Revised
	§33.15 Materials.	U
	§33.17 Fire protection.	T
	§33.19 Durability.	U
	§33.21 Engine cooling.	U
	§33.23 Engine mounting attachments and structure.	U
	§33.25 Accessory attachments.	U
	§33.27 Turbine, compressor, fan, and turbosupercharger rotor overspeed.	R
	§33.28 Engine control systems.	U
	§33.29 Instrument connection.	U
Subpart C—Design and Construction; Reciprocating Aircraft Engines		
	§33.31 Applicability.	U
	§33.33 Vibration.	U
	§33.34 Turbocharger rotors.	R
	§33.35 Fuel and induction system.	R
	§33.37 Ignition system.	R
	§33.39 Lubrication system.	U
Subpart D—Block Tests; Reciprocating Aircraft Engines		
	§33.41 Applicability.	U
	§33.42 General.	U
	§33.43 Vibration test.	U
	§33.45 Calibration tests.	U
	§33.47 Detonation test.	R - what is the equiv?

Subpart	Section	Applicable: Unchanged, Tailored, Revised
	§33.49 Endurance test.	R - based on thermo-structure. what might be equiv? Is a flight cycle the right equiv?
	§33.51 Operation test.	T - mostly applicable
	§33.53 Engine system and component tests.	T - §33.53(b)~ temp may not be the issue.
	§33.55 Teardown inspection.	U
	§33.57 General conduct of block tests.	U
Appendix A to Part 33—Instructions for Continued Airworthiness		

8.3. Airworthiness Standards: Normal Category Airplanes

8.3.1. Airworthiness Standards: Normal Category Airplanes, Subpart A, General

Table 16 shows applicability of FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart A, General, to electric propulsion.

Two of the sections are applicable and need not change for electric propulsion. Only one of the sections, 23.2410, Powerplant installation hazard assessment should be tailored for electric propulsion units.

Table 16 - Applicability of FAR 23, Subpart A, to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart A—General		
	§ 23.2000 Applicability and definitions.	U
	§23.2005 Certification of normal category airplanes.	U
	§23.2410 Powerplant installation hazard assessment.	T - tailored for electric propulsion units

8.3.2. Airworthiness Standards: Normal Category Airplanes, Subpart B, Flight

Table 17 shows applicability of FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart B, Flight, to electric propulsion.

All of the sections in Subpart B are applicable to electric propulsion, unchanged.

Table 17 - Applicability of FAR 23, Subpart B, to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart B—Flight		
Performance		
	§23.2100 Weight and center of gravity.	U
	§23.2105 Performance data.	U
	§23.2110 Stall speed.	U
	§23.2115 Takeoff performance.	U
	§23.2120 Climb requirements.	U
	§23.2125 Climb information.	U
	§23.2130 Landing.	U
Flight Characteristics		
	§23.2135 Controllability.	U
	§23.2140 Trim.	U
	§23.2145 Stability.	U
	§23.2150 Stall characteristics, stall warning, and spins.	U
	§23.2155 Ground and water handling characteristics.	U
	§23.2160 Vibration, buffeting, and high-speed characteristics.	U
	§23.2165 Performance and flight characteristics requirements for flight in icing conditions.	U

8.3.3. Airworthiness Standards: Normal Category Airplanes, Subpart C, Structures

Table 18 shows applicability of FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart C, Structures, to electric propulsion.

Twelve of the sections are applicable and need not change for electric propulsion, and none need be revised. Only three sections need to be tailored.

In Structural Loads, two of the sections, 23.2215 and 23.2225 should be tailored for electric propulsion units. In 23.2215 only one of the paragraphs, [c] should be tailored as it relates to asymmetric thrust from failure of powerplant unit, while paragraphs [a] and [b] are unchanged. In 23.2225, only paragraph [a] engine mounting should be tailored, while paragraphs [b] and [c] are unchanged.

In Structural Performance, only one section 23.2240 should be tailored with respect to paragraph [d] regarding high-energy fragments from an uncontained engine or rotating machinery failure.

Table 18 - Applicability of FAR 23, Subpart C, to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart C—Structures		
	§23.2200 Structural design envelope.	U
	§23.2205 Interaction of systems and structures.	U
Structural Loads		
	§23.2210 Structural design loads.	U
	§23.2215 Flight load conditions.	T - tailored for electric propulsion units re [c] asymmetric thrust from failure of powerplant unit ([a] and [b] are applicable unchanged)
	§23.2220 Ground and water load conditions.	U
	§23.2225 Component loading conditions.	T - tailored for electric propulsion units re [a] engine mounting ([b] and [c] are applicable unchanged)

Subpart	Section	Applicable: Unchanged, Tailored, Revised
	§23.2230 Limit and ultimate loads.	U
Structural Performance		
	§23.2235 Structural strength.	U
	§23.2240 Structural durability.	T - tailored for electric propulsion units re [d] high-energy fragments from an uncontained engine or rotating machinery failure
	§23.2245 Aeroelasticity.	U
Design		
	§23.2250 Design and construction principles.	U
	§23.2255 Protection of structure.	U
	§23.2260 Materials and processes.	U
	§23.2265 Special factors of safety.	U
Structural Occupant Protection		
	§23.2270 Emergency conditions.	U

8.3.4. Airworthiness Standards: Normal Category Airplanes, Subpart D, Design & Construction

Table 19 shows applicability of FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart D, Design & Construction, to electric propulsion.

Six of the sections are applicable and need not change for electric propulsion and none require revision.

In Fire and High Energy Protection, there are two of the three sections that need tailoring. Section 23.2330 should be tailored for electric propulsion units, and 23.2335 should be tailored for lightning protection for electric propulsion units.

Table 19 - Applicability of FAR 23, Subpart D, to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart D—Design and Construction		
	§23.2300 Flight control systems.	U
	§23.2305 Landing gear systems.	U
	§23.2310 Buoyancy for seaplanes and amphibians.	U
Occupant System Design Protection		
	§23.2315 Means of egress and emergency exits.	U
	§23.2320 Occupant physical environment.	U
Fire and High Energy Protection		
	§23.2325 Fire protection.	U
	§23.2330 Fire protection in designated fire zones and adjacent areas.	T - tailored for electric propulsion units
	§23.2335 Lightning protection.	T - tailored for electric propulsion units and lightning protection

8.3.5. Airworthiness Standards: Normal Category Airplanes, Subpart E, Powerplant

Table 20 shows the applicability of FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart E, Powerplant, to electric propulsion.

One section, §23.2430 Fuel systems, must be revised. And while much of this section addresses fuel as a subsystem to the aircraft system, there are some portions that refer to jettisoning fuel that is not applicable. However, paragraph (c) does reflect "recharging system" in the context of fuel storage refilling, and should be considered in the context of an electric propulsion system, as opposed to auxiliary power systems.

There are two sections that require tailoring: §23.2435 Powerplant induction and exhaust systems and §23.2440 Powerplant fire protection. While these are both focused on reciprocating engine systems, they should be made appropriate to electric propulsion systems.

Table 20 - Applicability of FAR 23, Subpart E, to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart E—Powerplant		
	§23.2400 Powerplant installation.	U
	§23.2405 Automatic power or thrust control systems.	U
	§23.2410 Powerplant installation hazard assessment.	U
	§23.2415 Powerplant ice protection.	U
	§23.2420 Reversing systems.	U
	§23.2425 Powerplant operational characteristics.	U
	§23.2430 Fuel systems.	R - make applicable to Electric Prop
	§23.2435 Powerplant induction and exhaust systems.	T - cooling applicable for Electric Prop
	§23.2440 Powerplant fire protection.	T - FP applicable to electric prop systems

8.3.6. Airworthiness Standards: Normal Category Airplanes, Subpart F, Equipment

Table 21 shows applicability of FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart F, Equipment, to electric propulsion.

Six of the sections are applicable and need not change for electric propulsion, nor are there any sections that require revision.

Three of the sections, 23.2515, 23.2520, and 23.2525, should be tailored for electric propulsion units. These have to do with distinguishing the electric propulsion units from other electrical and electronic systems for lightning; HIRF; and power generation, storage and distribution.

Two of the sections, 23.2540 and 23.2550, should be tailored for flight into icing conditions and accounting for uncontained fragments associated with equipment containing high-energy rotors.

Table 21 - Applicability of FAR 23, Subpart F, to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart F—Equipment		
	§23.2500 Airplane level systems requirements.	U
	§23.2505 Function and installation.	U
	§23.2510 Equipment, systems, and installations.	U
	§23.2515 Electrical and electronic system lightning protection.	T - tailored for electric propulsion units to distinguish from other electrical and electronic system
	§23.2520 High-intensity Radiated Fields (HIRF) protection.	T - tailored for electric propulsion units to account for HIRF
	§23.2525 System power generation, storage, and distribution.	T - tailored for electric propulsion units to distinguish from other electrical and electronic system
	§23.2530 External and cockpit lighting.	U
	§23.2535 Safety equipment.	U
	§23.2540 Flight in icing conditions.	T - tailored for electric propulsion units to account for icing
	§23.2545 Pressurized systems elements.	U
	§23.2550 Equipment containing high-energy rotors.	T - tailored for electric propulsion units to account for uncontained fragments

8.3.7. Airworthiness Standards: Normal Category Airplanes, Subpart G, Flightcrew Interface and Other Information

Table 22 shows applicability of FAR 23, Airworthiness Standards: Normal Category Airplanes, Subpart G, Flightcrew Interface and Other Information, to electric propulsion.

Three of the sections are applicable and need not change for electric propulsion, nor are there any sections that need be revised.

Two sections, 23.2600, Flightcrew interface, and 23.2615, Flight, navigation, and powerplant instruments, should both be tailored for electric propulsion units to account for proper powerplant information display.

Table 22 - Applicability of FAR 23, Subpart G, to Electric Propulsion

Subpart	Section	Applicable: Unchanged, Tailored, Revised
Subpart G—Flightcrew Interface and Other Information		
	§23.2600 Flightcrew interface.	T - tailored for electric propulsion units to account for proper powerplant display
	§23.2605 Installation and operation.	U
	§23.2610 Instrument markings, control markings, and placards.	U
	§23.2615 Flight, navigation, and powerplant instruments.	T - tailored for electric propulsion units to account for proper powerplant display
	§23.2620 Airplane flight manual.	U
Appendix A to Part 23—Instructions for Continued Airworthiness		

8.4. Compilation of Elements of the Applicable FARs that Suggest Revisions

There are eight sections of FAR 33 and 23 that should be revised for electric propulsion. None of FAR 35 requires revision and only one section in FAR 23 requires revision. Seven of the eight sections that require revision are in FAR 33. The sections are summarized in Table 23.

Table 23 - Summary of FAR Sections to be Revised for Electric Propulsion

FAR	Section	Applicable: Unchanged, Tailored, Revised
FAR 35, Propellers		
	None	
FAR 33, Aircraft Engines		
	§33.7 Engine ratings and operating limitations.	R - make §33.7(b) applicable to Electric Prop
	§33.27 Turbine, compressor, fan, and turbosupercharger rotor overspeed.	R
	§33.34 Turbocharger rotors.	R
	§33.35 Fuel and induction system.	R
	§33.37 Ignition system.	R
	§33.47 Detonation test.	R - what is the equiv?
	§33.49 Endurance test.	R - based on thermo-structure. what might be equiv? Is a flight cycle the right equiv?
FAR 23, Normal Category Airplanes, Subpart A—General		
	None	
FAR 23, Normal Category Airplanes, Subpart B—Flight		
	None	
FAR 23, Normal Category Airplanes, Subpart C—Structures		
	None	
FAR 23, Normal Category Airplanes, Subpart D—Design and Construction		
	None	
FAR 23, Normal Category Airplanes, Subpart E, Powerplant		
	§23.2430 Fuel systems.	R - make applicable to Electric Prop

FAR	Section	Applicable: Unchanged, Tailored, Revised
FAR 23, Normal Category Airplanes, Subpart F—Equipment		
	None	
FAR 23, Normal Category Airplanes, Subpart G—Flightcrew Interface and Other Information		
	None	

8.5. Compilation of Elements of the Applicable FARs that Suggest Tailoring

There are 20 sections in FAR 35, 33 and 23 that should be tailored for electric propulsion. Two of the sections in FAR 35 should be tailored for electric propulsion and three of the sections in FAR 33 should be tailored. Fifteen of the sections in FAR 23 should be tailored for electric propulsion across six of the seven subparts in FAR 23. The sections are summarized in Table 24.

Table 24 - Summary of FAR Sections to be Tailored for Electric Propulsion

FAR	Section	Applicable: Unchanged, Tailored, Revised
FAR 35, Propellers		
	§35.39 Endurance test.	T - see §33.49
	§35.40 Functional test.	T - see §35.39
FAR 33, Aircraft Engines		
	§33.17 Fire protection.	T
	§33.51 Operation test.	T - mostly applicable
	§33.53 Engine system and component tests.	T - §33.53(b)~ temp may not be the issue.
FAR 23, Normal Category Airplanes, Subpart A—General		
	§23.2410 Powerplant installation hazard assessment.	T - tailored for electric propulsion units
FAR 23, Normal Category Airplanes, Subpart B—Flight		
	None	

FAR	Section	Applicable: Unchanged, Tailored, Revised
FAR 23, Normal Category Airplanes, Subpart C—Structures		
	§23.2215 Flight load conditions.	T - tailored for electric propulsion units re [c] asymmetric thrust from failure of powerplant unit ([a] and [b] are applicable unchanged)
	§23.2225 Component loading conditions.	T - tailored for electric propulsion units re [a] engine mounting ([b] and [c] are applicable unchanged)
	§23.2240 Structural durability.	T - tailored for electric propulsion units re [d] high-energy fragments from an uncontained engine or rotating machinery failure
FAR 23, Normal Category Airplanes, Subpart D—Design and Construction		
	§23.2330 Fire protection in designated fire zones and adjacent areas.	T - tailored for electric propulsion units
	§23.2335 Lightning protection.	T - tailored for electric propulsion units and lightning protection
FAR 23, Normal Category Airplanes, Subpart E, Powerplant		
	§23.2435 Powerplant induction and exhaust systems.	T - cooling applicable for Electric Prop
	§23.2440 Powerplant fire protection.	T - FP applicable to electric prop systems
FAR 23, Normal Category Airplanes, Subpart F—Equipment		

FAR	Section	Applicable: Unchanged, Tailored, Revised
	§23.2515 Electrical and electronic system lightning protection.	T - tailored for electric propulsion units to distinguish from other electrical and electronic system
	§23.2520 High-intensity Radiated Fields (HIRF) protection.	T - tailored for electric propulsion units to account for HIRF
	§23.2525 System power generation, storage, and distribution.	T - tailored for electric propulsion units to distinguish from other electrical and electronic system
	§23.2540 Flight in icing conditions.	T - tailored for electric propulsion units to account for icing
	§23.2550 Equipment containing high-energy rotors.	T - tailored for electric propulsion units to account for uncontained fragments
FAR 23, Normal Category Airplanes, Subpart G—Flightcrew Interface and Other Information		
	§23.2600 Flightcrew interface.	T - tailored for electric propulsion units to account for proper powerplant display
	§23.2615 Flight, navigation, and powerplant instruments.	T - tailored for electric propulsion units to account for proper powerplant display

The technical analyses and testing to support the revisions and tailoring are technical challenges that form the foundation of a technology approach to their resolution.

9. Conclusion

A process of regulatory review can be applied to emerging technology and vehicle concepts, where the technology can influence the regulations and certification criteria, predominantly by affecting the means of compliance. The knowledge gained from the technology development effort and its effect on developing a methodology for assessing the goodness of the design by rigorous, and appropriate-for-the-technology test methods.

This report shows a method whereby a general assessment of the regulations is conducted for a technology, in this case, electric propulsion. The method assesses which regulations have no need of change, which regulations can be tailored to make them appropriate for the technology and which regulations need revision to make them relevant to the electric propulsion technology. The method is heuristic, in that is non-analytical, and it requires expertise in not only the technology but also the regulatory domain. This experience-based methodology is very appropriate for new technology efforts where an analytically optimal solution is not, yet, necessary.

For this case, most of the regulations were found to be appropriate for the technology area. Out of the 122 sections reviewed in FAR 35, 33 and 23, eight were found to need revision, and 20 would need tailoring for the electric propulsion technology. This provides some confidence that the regulatory process is robust in the presence of the new technology. It also means that the Means of Compliance will need to be agile to accommodate the new technology. Fortunately, with the *Small Airplane Revitalization Act of 2013*, the means by which standards are developed has been significantly improved by developing industry-Government consensus standards with the ASTM.

With this heuristic approach in place, a foundation can be established for an analytical approach to certification and regulation for the purpose of assessing the viability of new technologies. This analytic approach is not the substitute for certification, rather it becomes a tool for technology development organizations to understand the potential for a new technology to find its way into reality. An analytic method would be very beneficial for systems analyses of vehicle concepts to assess the safety of new and evolving vehicle concepts. It would offer a means to trade technology advancement with an analytical safety approach. Early efforts should be assessed heuristically, to assure that neither the technology assessment is too constrained and that the safety assertions are not overly optimistic.

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14. ABSTRACT
This report characterizes the certification practices for electric propulsion systems by modeling changes to current engine and propeller certification practices (14 CFR 23, 33 and 35 and means of compliance in standards developed by ASTM Committee F39 and F44). Industry technology paths are varied, so this report focuses on insights from the NASA X-57 Maxwell Distributed Electric Propulsion flight demonstrator system technology project. There are 122 sections of the regulation reviewed, where 28 needed tailoring or revision. A second report will examine the regulations to the X-57 system development products. A final report will describe a general regulatory gaps method for new vehicle concepts.

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X-57; certification; distributed; electric; propulsion; standards

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