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X-57 Maxwell Airworthiness Validation Plan

Herbert W. Schlickenmaier
HS Advanced Concepts LLC
950 N Washington Street, Suite 331, Alexandria, VA 22314

Mark Anderson
Flight Test Solutions, LLC

Evan Harrison
Georgia Institute of Technology

Edwin H. Hooper
Aviation Consultant, Inc

Jeff Knickerbocker
Sunrise Certification and Consulting, Inc.

Micah Larson
Empirical Systems Aerospace

James Lawson
Lawson SYS

Mark Voss
Thermodynamic Sciences LLC

Ron Wilkinson
AvSouth LLC

Jay Turnberg
Turndyne, Inc.

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EXECUTIVE SUMMARY

This report is a Final Airworthiness Validation Plan (AVP) and describes how an aircraft like X-57 does (and does not) meet current airworthiness standards. The objective of this report is to create an example certification basis, associated means of compliance (MoC), and method of compliance for a distributed electric propulsion airplane under 14 Code of Federal Regulations (CFR) Part 21, "Certification Procedures for Products and Articles," and its associated relevant sections of 14 CFR for "Airworthiness Standards" of Part 23, "Normal Category Airplanes," Part 33 "Aircraft Engines," and Part 35 "Propellers." The approach to meet the objective is to use NASA's X-57 Modification (Mod) IV flight demonstrator as an example and categorize its applicability to the regulations and standards according to the following three conditions: 1. Identify, where applicable, that the MoC and methods of compliance can be associated with existing Standard Specifications and Standard Practices of (ASTM) Committee F39 on Aircraft Systems and ASTM Committee F44 on General Aviation Aircraft; 2. If relevant ASTM standards do not exist, identify means and-or methods of compliance from appropriate Federal Aviation Administration (FAA) Advisory Circulars and other sources to use for the X-57 Mod IV vehicle; or 3. If no relevant certification rule, MoC, or method of compliance exists, highlight this omission and provide recommendations.

This AVP report is modeled after a typical certification basis document used in the industry to provide a civil aviation authority with the intended approach to meet the applicable regulations for the aerospace product. While the X-57 will not go into production and thus is not pursuing an aircraft type certificate, the format for this report provides a clear structure to expose gaps in the current regulations and standards, organized along the lines of the regulations and the associated standards.

In particular, the benefits of the Distributed Electric Propulsion (DEP) system are spawning the development of standards that support its technology opportunity with the necessary means to comply with its safe design and operation. Currently, there are no standards for DEP. Therefore the work of the ASTM F44.40 Powerplant Subcommittee has established a working group to assess the effect of DEP on two Electric Propulsion Unit (EPU) standards, F3316 and F3239.

The EPUs that are part of the X-57 are well-positioned to inform the efforts in ASTM F44.40 on F3316 and F3239 and the seminal work in ASTM F39.05 on F3338.

In November 2020, the FAA issued the first set of special conditions for a 375 and 750 SHP EPU in the certification process by magniX. Given that both electric motors are designed to accept propellers and rely on 2×3-phase inverter architecture for redundancy, this Special Condition applies to the X-57 in most respects.

The new and novel features of the magniX EPUs that led to the decision to produce special conditions are best explained in the text published in the Federal Register. Given the performance-based tone of the magniX special conditions, the F3338 specification becomes highly complementary to the Special Conditions, which is an objective many, both in industry and the various certification authorities, have sought to accomplish. One fundamental assumption made in both the magniX special conditions and F3338 is the consideration of the electric motor and the motor controller as an inseparable pairing. As noted in F3338-20, the motor inverter and the motor controller are typically physically integrated into a single package. Therefore, the term controller will

refer to either or both in this text. Generally, the application of standards based on the ASTM Standard ASTM F3338, Design of Electric Propulsion Units for General Aviation Aircraft, aligned with the magniX special conditions and applied to the X-57.

Electric Storage Systems (ESS) are a gap in the current standards, and some insights from the regulations on fuel storage and fuel systems can be used as metaphors for ESS, but that gap is profound in the current rules. The work that ASTM F39.05 is applying to ESS in the form of Guidelines is evolving. Currently, the work that the RTCA did is considered the only acceptable MoC, despite its origins in Part 25 applications of Equipment.

Beyond these general commentaries, this report has identified "Key Challenges" based on the in-depth review of the regulations and MoC in sections 2 through 4 of this report, addressing 14 CFR Parts 23, 33, and 35.

In addition to the work represented in this report, four areas deserve further consideration:

1. Incorporate Finalized Mod IV Specifications and Requirements into a Revised AVP
2. Continue Development of Standards to Address New Means of Compliance
3. Develop a Model-Based Systems Engineering Framework
4. Continue to Engage the FAA Certification Policy and Innovation Team

HS Advanced Concepts LLC developed a team of subject matter experts to assess the X-57 in such a way as to create this AVP. They are Mr. Mark Anderson, of Flight Test Solutions, LLC, specializing in Flight Test; Dr. Evan Harrison, of the Aerospace System Design Lab, Georgia Institute of Technology, specializing in Model-Based Systems Engineering; Mr. Edwin H. Hooper, of Aviation Consultant, Inc, specializing in Structures; Mr. Jeff Knickerbocker, of Sunrise Certification and Consulting, Inc., specializing in Electrical Systems; Mr. Micah Larson, of Empirical Systems Aerospace (X-57 Prime Contractor), as the Certification Liaison; Mr. James Lawson, of Lawson SYS, specializing in Systems Safety Analysis; Mr. Mark Voss, of Thermodynamic Sciences LLC, specializing in Aircraft Engines; Mr. Ron Wilkinson, of AvSouth LLC, specializing in Powerplant; and Mr. Jay Turnberg, of Turndyne, Inc., specializing in Propellers.

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1 Introduction

This report is a Final Airworthiness Validation Plan (AVP) and describes how an aircraft like X-57 does (and does not) meet current airworthiness standards. The objective of this report is to create an example certification basis, associated means, and method of compliance for a distributed electric propulsion airplane under 14 CFR Part 21, “Certification Procedures for Products and Articles,” and its associated relevant sections of 14 CFR for “Airworthiness Standards” of Part 23, “Normal Category Airplanes,” Part 33 “Aircraft Engines,” and Part 35 “Propellers.” The approach to meet the objective is to use NASA’s X-57 Mod IV flight demonstrator as an example and categorize its applicability to the regulations and standards according to the following three conditions:

1. Identify, where applicable, that the means of compliance and methods of compliance can be associated with existing Standard Specifications and Standard Practices of ASTM Committee F39 on Aircraft Systems and ASTM Committee F44 on General Aviation Aircraft;
2. If relevant ASTM standards do not exist, identify means and-or methods of compliance from appropriate FAA Advisory Circulars and other sources to use for the X-57 Mod IV vehicle; or
3. If no appropriate certification rule, means of compliance, and-or method of compliance exists, highlight this omission and provide recommendations.

Of particular interest are those areas where standards are nonexistent or otherwise not clearly defined for distributed electric propulsion architectures since this is where the X-57 project may be able to add the most value.

This report is the third in this series of four reports. The first report in the series is the “Draft Airworthiness Validation Plan,” delivered in January 2020, followed by the “Draft X-57 Reference to Compliance Checklist,” produced in March 2020. These two reports set the foundation for the methodology. The fourth and final report series is the “Final X-57 Reference to Compliance Checklist.” The Compliance Checklist report creates a cross-reference between the existing X-57 system and subsystem requirements to the compliance checklist (rules and means of compliance) and verification artifacts (methods of compliance) to the “Airworthiness Validation Plan” report.

The NASA X-57 “Knowledge Management Plan” (KMP-CEPT-018) describes how these two reports transfer their products, as well as the timing and depth of delivery of specific technology products (to ensure the protection of intellectual property), and finally describes the sources and repositories of the products.

This AVP report is modeled after a typical certification basis document used in the industry to provide a civil aviation authority with the intended approach to meet the applicable regulations for the aerospace product. While the X-57 will not go into production and thus is not pursuing an aircraft type certificate, the format for this report provides a clear structure to expose gaps in the current regulations and standards, organized along the lines of the regulations and the associated standards.

1.1 The X-57 Distributed Electric Propulsion Flight Demonstration Vehicle

While the X-57 is an experimental flight research vehicle, it is a derivative of the Tecnam P2006T. The Tecnam P2006T is certified under Title 14 of the Code of Federal Regulations (CFR) Part 23 (with an aircraft type certificate from the European Union Aviation Safety Agency (EASA) of EASA.A.185 and the FAA of A62CE). It is a twin-engine aircraft with Rotax 912S3 internal combustion engines (each with an engine Type Certificate Data Sheet E00051EN) certified under 14 CFR Part 33. The engines are approved to use either MOGAS (meeting ASTM D4814, minimum RON 95) or 100LL AVGAS (meeting ASTM D910). Figure 1 shows a photograph of the NASA-purchased Tecnam P2006T.

Figure 1. NASA-Purchased Tecnam P2006T

The modification of the Tecnam P2006T into the NASA X-57 occurs in modification stages (called “Mod’s”). The first Mod (Mod II) replaces the two Rotax motors with two Joby electric engines. Three of the four seats are removed and replaced with an electric storage system consisting of batteries. The next Mod (Mod III-IV) replaces the original wing with a high-aspect-ratio one, and the two Joby electric engines move from mid-span to the wingtips. Next, at Mod III-IV, 12 motors are placed along the wing’s leading edge to act as high-lift devices by producing distributed electric propulsion (DEP) (a vital feature of the flight research vehicle). Figure 2 shows the characteristics of the Tecnam P2006T to the X-57. Figure 3 shows an artist’s rendition of the Mod IV X-57 in front of the hangar at Armstrong Flight Research Center.

Figure 2. A Planform Comparison of the Tecnam P2006T to the X-57 DEP Mod IV Configuration

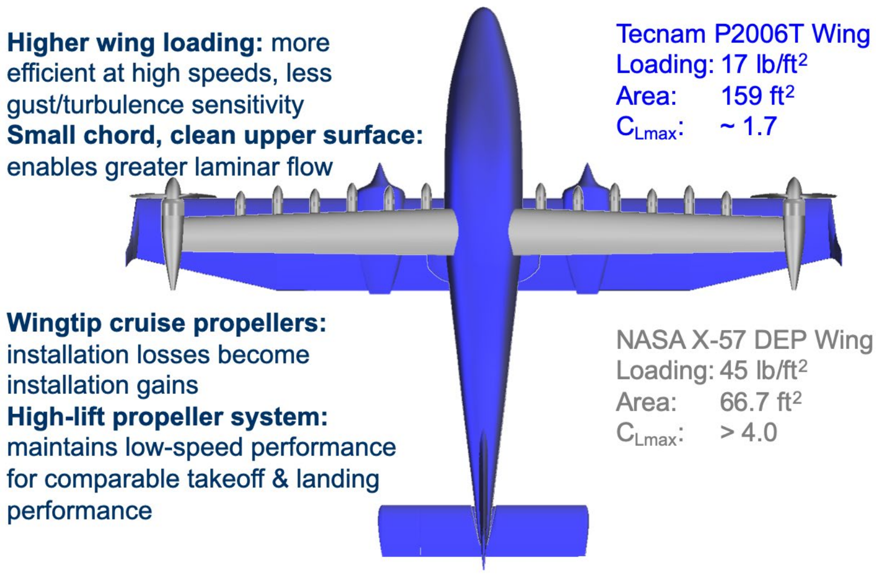


Figure 3. Artist's Rendition of the NASA X-57 Mod IV Distributed Electric Propulsion Flight Demonstrator

This report aims to collect the relevant considerations of the X-57 Distributed Electric Propulsion Flight Demonstrator and assess it against the US Federal Aviation Regulations (FAR) and the associated ASTM Means of Compliance. The regulations are in Title 14 of the CFR Part 23, "Airworthiness Standards for Normal Category Aircraft;" Part 33, "Airworthiness Standards for Aircraft Engines;" and Part 35, "Airworthiness Standards for Propellers." Since the current regulations for aircraft engines only describe reciprocating and turbine engines, this report is the first public application of a Special Condition for Electric Engines[1] published in the Federal

[1] Federal Register, Docket ID FAA-2020-0894, *magniX USA, Inc., magni250 and magni500 Model Engines,* Notice of Proposed Special Conditions, Published November 19, 2020, with comments closing on December 21, 2020. See https://www.federalregister.gov/documents/2020/11/19/2020-23434/special-conditions-magnix-usa-inc-magni250-and-magni500-model-engines

Register used in place of 14 CFR Part 33. (This report will reference other Civil Aviation Authorities as appropriate.)

This report has four overarching topics in the introduction. The first is System Safety (Section 1.2), and the second is Software Assurance (Section 1.3). While these topics are in the regulations and standards, their cross-cutting nature is essential for the X-57. The third topic describes the potential of Model-Based Systems Engineering (MBSE) (Section 1.4). Model-Based Systems Engineering promises to handle the dynamic nature of gaps in regulations and evolving standards in the presence of advanced technology concepts. The concluding topic in the introduction shows how the X-57 uniquely contributes to the existing body of knowledge for developing certification basis (Section 1.5).

1.2 System Safety

For experimental aircraft such as the X-57, airworthiness is approved by satisfying the requirements necessary to obtain a special airworthiness certificate. Except for identifying potential safety hazards, this process requires very little in terms of a system safety analysis. However, it limits the operation of the aircraft to an approved flight test area and does not allow the carriage of passengers or property for compensation or hire. The alternative, i.e. satisfying the requirements to obtain a standard airworthiness certificate, is much more burdensome. The following referenced material details the system safety analysis aspects of this process:

- SAE ARP 4754A, *Guidelines for Development of Civil Aircraft and Systems*
    - Recognized by AC 20-174 as an acceptable means of compliance
    - Being updated by SAE S18 to ARP 4754B
- SAE ARP 4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne System and Equipment*
    - Recognized by ARP 4754
    - Being updated by SAE S18 to ARP 4761A
- ASTM F3061-17, *Standard Specification for Systems and Equipment in Small Aircraft*
- ASTM F3230-17, *Standard Practices for Safety Assessment for Systems and Equipment in Small Aircraft*
- SAE AIR6913, *Using STPA During Development and Safety Assessment of Civil Aircraft*
- ASTM WK60748, *New Guide for Application of Systems-Theoretic Process Analysis to Aircraft*
- ASTM WK52829 *Standard Practice for Simplified Safety Assessment of Systems and Equipment in Small Aircraft*
- SAE AIR6219, *Incorporation of Atmospheric Neutron Single Event Effects Analysis into a Safety Assessment*
- In-service safety assessment
    - ARP5150, i.e. transport airplanes
    - ARP5151, i.e., general aviation and rotorcraft

The above-referenced material would be prohibitive if it were required for an experimental aircraft such as the X-57. However, there is interest in learning from the X-57 to develop an approach that would be less prohibitive and adaptable to novel aircraft types.

The following sections discuss how a complete paradigm shift to an approach that integrates the system safety analysis with developing a certification basis and means of compliance is necessary.

1.2.1 Introduction to System Safety

The X-57 introduces distributed electric propulsion, a novel application of electric propulsion technology. However, this is just one example of a novel aircraft type. Recent developments in electric and hybrid-electric technology have resulted in many novel aircraft types, including electric Vertical Takeoff and Landing (VTOL) and Short Takeoff and Landing (STOL) and aircraft with energy storage systems that use battery cells with exotic chemistry and-or hydrogen fuel cells. At the same time, advances in autonomy systems have replaced many pilot functions with technology.

The net result is a divergence in the variety of system architecture possibilities. This divergence is a challenge to a certification approach dependent on establishing a certification basis and means of compliance before the certification of an aircraft type. Despite there being a mechanism to develop a certification basis under 21.17(b) where one doesn't exist, this approach is burdensome to all stakeholders. Furthermore, it has never had to accommodate the number of novel aircraft types expected due to advances in electric propulsion systems and powertrains and their simplicity compared to reciprocating and turbine engines.

Traditionally, novel technologies and applications of technologies have been accommodated via special conditions. It is necessary to understand the intent of these regulatory requirements to develop special conditions that achieve an equivalent level of safety to existing regulatory requirements. The plan can be summarized as achieving a societally acceptable level of safety assurance. Therefore, special conditions, new certification basis, and new means of compliance must be harmonized with the system safety analysis.

It is a misconception that Part 23 Amendment 64 is a performance-based requirements framework. In reality, many of the requirements in Amendment 62 do not exist in Amendment 64. Instead, it is an abstraction of Amendment 62, which eliminates a requirements tier. It accommodates a wider variety of system architectures by being less prescriptive. However, the missing tier leaves a void because systems engineering and software and complex hardware design assurance processes dictate that there is traceability from safety assurance objectives, through requirements tiers, to the software and complex hardware.

The proposal is that a holistic safety analysis, similar to that advocated by Moak[2], L. et al. (2020), is leveraged to derive requirements that bridge the gap and are consistent with safety assurance objectives.

1.2.2 Approach to System Safety, Failure Modes

The failure modes identified by the system safety analysis are system architecture agnostic. The effect of the failure modes is different depending on the system architecture. By separating the failure modes from the effect of the failure modes, it is possible to develop guidance that applies to novel aircraft types that utilize similar technology regardless of whether they have similar system architectures. Therefore, if the emphasis is on the identification of failure modes, it is

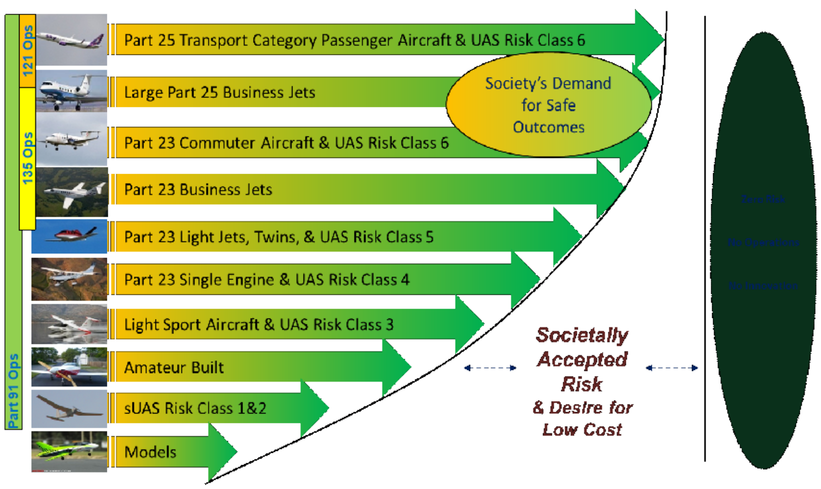
[2] Official Report of the Special Committee to Review the Federal Aviation Administration's Aircraft Certification Process, January 16, 2020, http://flighttestsafety.org/images/FINAL_SCC_Report_Jan16_20201.pdf

possible to develop a certification basis and means of compliance that can be applied to all-electric and hybrid-electric aircraft types that use similar technologies such as electric propulsion systems and powertrains and autonomy systems. Independently, the effect of the failure modes can be assessed concerning the system architecture as part of the system safety analysis.

1.2.3 Approach to System Safety, The Safety Continuum

Airworthiness Standards for Normal Category Airplanes, as described in 14 CFR Part 23, Amendment 64, applies a safety continuum approach (shown in Figure 4) by adjusting safety assurance depending on the number of passengers an aircraft can accommodate. The safety assurance requirements rely on a probability budget and design assurance level. However, there is no correlation between where an aircraft type is on the safety continuum and the failure modes to which it is susceptible. Instead, to satisfy safety assurance requirements, the level of fault tolerance and redundancy and-or the failure rate requirements assigned to systems and equipment are adjusted.

Figure 4. Notional View of the Safety Continuum



Therefore, except for safety assurance requirements, the certification basis and means of compliance can be the same regardless of where an aircraft type is on the safety continuum.

An attempt has been made to impose different test procedures on energy storage systems depending on where an aircraft type is on the safety continuum. The safety continuum has been applied this way because the quantification of battery cell failure rates has historically been unsuccessful. However, instead of abandoning a fundamentally sound approach, it is suggested that an attempt is made to improve methodologies for quantifying battery cell failure rates.

1.2.4 Approach to System Safety, The Mitigation of Failure Modes

The association of mitigations with failure modes via regulatory requirements biases the selected mitigation. For example, a rotating blade departure can be mitigated by containment, reducing its RPM, or designing it to be more robust to failure. By specifying containment, the bias is away from other equally valid and-or safety-enhancing mitigations.

Requirements to mitigate failure modes without stating how to mitigate them are proposed.

Ideally, it should be possible to apply alternative mitigations without requiring special conditions. If mitigations are identified by a certification basis and-or means of compliance, they should be identified suggestively or with a mechanism to replace them with alternative mitigations.

1.2.5 Approach to System Safety, Single Failure Criteria

The single failure criteria requires that a single failure mode cannot prevent continued safe flight and landing. The single failure criteria are mentioned explicitly and implicitly by existing acceptable means of compliance. Explicitly, failure modes are identified, and there are requirements that these failure modes do not cause a catastrophic failure condition. Implicitly, there are overarching statements that no single failure should cause a catastrophic failure condition and-or to prevent continued safe flight and landing.

Whether it is an explicit or an implicit requirement, the single failure criteria are verified via a fault tree analysis and a minimum cutset analysis. This is achieved by a detailed analysis of each AND gate. If the inputs to the AND gate are independent, the AND gate is valid. Once each AND gate has been validated, the minimum cutset analysis is examined to ensure no single event cutsets. Single event cutsets represent single failures that can prevent continued safe flight and landing.

The risk of attempting to identify every failure mode that the single failure criteria should be applied to is that failure modes that it does not need to be applied to are subjected to it, and others that it does need to be applied to are not.

Part 33 extends the single failure criteria to engine control systems' hazardous failure conditions, i.e., failure conditions that are not expected to prevent continued safe flight and landing. The proposal is that a more holistic approach is taken. Because the engine-electric propulsion system is expected to become a more integrated part of electric and hybrid-electric aircraft types, the single failure criteria are applied consistently.

1.2.6 Approach to System Safety, Operating Limits

The aircraft type should be capable of operating within its certified operating limits. The operating limits bound the system safety analysis. Consequently, it is invalid if an aircraft type is operated outside its operational limits. However, the certification basis and means of compliance cannot define the operating limits because there are no common standard operating limits that apply to all aircraft types. Therefore, the proposal is that the certification basis and means of compliance identify the operating limit variables that need to be quantified—for example, temperature, torque, and speed for an electric propulsion system. The operating limits set upper and lower bounds for over and under temperatures, overtorque and overspeed, respectively. It should not be possible to exceed these bounds unless there is a failure mode, human error, or combination thereof that has been assessed by the system safety analysis.

The operating limits should include the flight envelope and environmental conditions. Environmental conditions should consist of an endurance component. The operating limits should be verified by analysis and-or testing. Credit is taken for the aircraft flight manual and operating procedures, emergency operating procedures, and checklists. The aircraft flight manual should be supported by training and human factor studies to verify that tasks don’t require exceptional pilot skill or strength. Pilot workload, skill, and strength should be evaluated across the full spectrum of pilots, and training should be comprehensive and repetitive.

1.2.7 Approach to System Safety, Requirements Derivation

Traditionally, the system safety analysis has been used to derive and validate-verify requirements. System safety analysis techniques derive probability budgets, single failure criteria requirements, and design assurance level requirements that can be applied to software and complex hardware development processes. In addition to traditional techniques, model-based systems/safety techniques and control theory can be used to derive control actions and unsafe control actions. An approach that is gaining popularity is Systems Theoretic Process Analysis (STPA); this approach derives unsafe control actions that can be associated with failure modes and human errors. Consequently, mitigations can be selected that prevent these unsafe control actions.

If the unsafe control actions can be abstracted, associated failure modes and human errors, along with a list of potential mitigations can be developed that apply to a wider variety of system architectures. The proposal is that a model-based systems-safety approach is used to abstract versions of the constituent parts of a typical system architecture to assist in identifying failure modes.

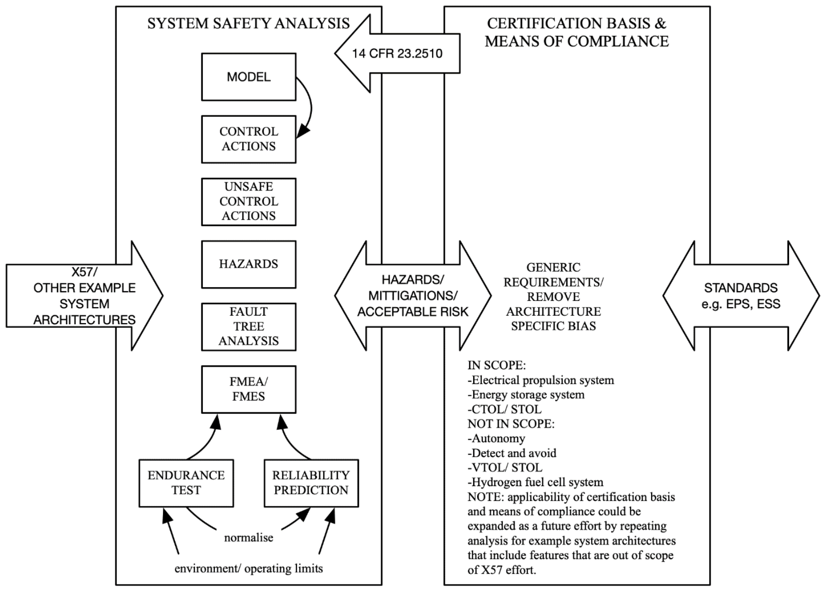
1.2.8 Summary

The critical aspects of an approach that integrates the system safety analysis with the development of a certification basis and means of compliance are as follows:

- Failure modes, not the effect of the failure modes, should be identified by the certification basis and means of compliance.
- The safety continuum should not be applied beyond the probability budget and design assurance level.
- An approach that explicitly identifies failure modes to which the single failure criteria should be applied is unnecessary.
- Mitigations should be suggestive, and-or there should be a mechanism to replace them with alternate mitigations without requiring special conditions.
- The operating limit variable should be identified to set upper and lower bounds. It should not be possible to exceed these bounds unless there is a failure mode, human error, or combination thereof that the system safety analysis has assessed.
- Model-based systems/safety techniques should augment traditional system safety analysis techniques to assist in identifying failure modes and human errors.

The system safety analysis approach, depicted in Figure 5, identifies the technologies that are {in|not-in} scope, i.e., the technologies that regulatory requirements can be derived for by applying the integrated system safety analysis approach to the X-57. However, the process can be expanded to other system architectures.

Figure 5. Integrated System Safety Analysis Process



1.3 Software (SW) Assurance

This section addresses the top-3 benefits and top-3 issues with the use of DO-178 and the proposed ASTM F39 standard for software validation[3]. Along with the table, a short discussion.

The X-57 team needs to see the software Verification and Validation (V&V) design space as it wrestles with software challenges for something like a high-lift motor controller. For example, from ASTM Subcommittee F39.05 on Design, Alteration, and Certification of Electric Propulsion Systems F3338-18, Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft, regarding EPU Controls: "5.10.1 The software and complex electronic hardware, including programmable logic devices, shall be designed and developed using a structured and methodical approach that provides a level of assurance for the logic, that is commensurate with the hazard associated with the failure or malfunction of the systems in which the devices are located, and is substantiated by a verification confirmation, through the collection and review of objective evidence, that specified requirements have been fulfilled."

1.3.1 Fundamental Problems for Software

- Solutions implemented in software are complex – complex systems are difficult, if not impossible, to prove correct.
- ***Testing does not/cannot prove an absence of errors*** (*testing will only reveal error conditions that are excited with a specific stimulus in the test environment*)**.**
- Creating viable, complex systems is labor intensive (expensive), even with myriad assistive tools. (*An addition, will the tools provide the correct output? As well, tools are not cheap – especially proven tools.*)

[3] ASTM does not actually address software validation.

- Unless working in the consumer or automotive market, non-recurring software development and verification costs are challenging to amortize. For example, consider ***highly*** successful commercial aircraft programs such as the B737 or A320 families. Assuming all software was the same for all aircraft models, which it isn't, non-recurring development costs can only be spread across several thousand platforms at best.
- Software maintenance is difficult and expensive over a typical commercial aircraft's life (*must maintain it as long as it is flying*).

1.3.2 Options to Satisfy ASTM Guidance

1. Formal Theorems and Proofs (*NASA advocates this approach for some domains. However, formal methods frequently do not scale well to more significant problems and typically require engineers with at least graduate degrees; Unfortunately, the US workforce is not conversant in Formal Methods.*)
2. Common Software Process Assurance Methodologies (*non-exhaustive but several of the more common approaches*)
   a. RTCA/DO-178C
   b. ISO 12207/15288 (*intent is similar to 4754A/DO-178C but not specific to airborne systems*)
   c. SEAL (*Lockheed-Martin/JSF with Navy buy-in – very DO-178C-like*)
   d. ISO 26226 (*automotive – very DO-178C-like*)
   e. ED-153 (*EUROCAE, high-level framework for ground-based aviation systems, not specific but requires the adoption of DO-178C or DO-278A like approach*)
3. Applicant developed SW assurance strategies (*Develop your own approach and attempt to convince CAA it is "good enough" – this can often prove more difficult than simply adopting an accepted standard.*)

1.3.3 Considerations for Application of DO-178C

Table 1 compares the benefits and concerns when considering the application of DO-178C to an aircraft certification program.

Table 1. The Pros and Cons of Applying DO-178

DO-178C Pros and Cons	
Pro	**Con**
Allows for multiple levels of criticality (*Levels A through D, where Level A is addressing "catastrophic hazards" and Level D is targeted for nothing more severe than "minor hazards"*) which can reduce level of process rigor as software criticality drops.	Perceived to be expensive. (*And it can be very expensive when executed poorly, without good system processes and requirements (e.g., SAE ARP 4754A) and adherence to excellent software engineering practices.*) Software engineers may tend to lose sight of product functionality in lieu of process compliance. (*Process compliance can become a primary focus as opposed to product function.*)
A very mature document, based on very sound software engineering principles, with a documented track record of creating "safe" software.	Though a very mature document, often misunderstood/misinterpreted. (S*oftware engineering seems to no longer be a priority in the US.*)

DO-178C Pros and Cons	
Pro	**Con**
Provides a means for detecting potentially latent and anomalous software implementation failures via a rigorous verification processes, especially for higher criticality software levels. *(This assumes System Requirements have been "validated".)*	To control scope, well thought out safety analyses (e.g., SAE ARP *4754A/4761 – architectural mitigation/partitioning*) and complete/correct system requirements must be available.
There is a defined completion criteria in terms of software verification. (*As opposed to "out of schedule and/or money"*.)	DO-178C verification processes are intensive and rigorous for higher criticality levels. Or simply put, expensive.
There is not a single, correct answer in terms of software process definition, rather a set of fairly detailed objectives to be satisfied. (*Allows for competitive exploration.*)	There is not a single, correct answer in terms of software process definition, rather a set of fairly detailed objectives to be satisfied. (*There is no "cookbook" with "how to" answers.*)

Table 2 shows the four most expensive objectives in DO-178C, which are all related to the verification of software.

Table 2. The Four Most Expensive Objectives in DO-178C Related to Verification

	Objective		Activity	Applicability by Software Level				Output		Control Category by Software Level			
	Description	Ref	Ref	A	B	C	D	Data Item	Ref	A	B	C	D
1	Executable Object Code complies with high-level requirements.	6.4.a	6.4.2 6.4.2.1 6.4.3 6.5	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②
								Trace Data	11.21	①	①	②	②
2	Executable Object Code is robust with high-level requirements.	6.4.b	6.4.2 6.4.2.2 6.4.3 6.5	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②
								Trace Data	11.21	①	①	②	②
3	Executable Object Code complies with low-level requirements.	6.4.c	6.4.2 6.4.2.1 6.4.3 6.5	●	●	○		Software Verification Cases and Procedures	11.13	①	①	②	
								Software Verification Results	11.14	②	②	②	
								Trace Data	11.21	①	①	②	
4	Executable Object Code is robust with low-level requirements.	6.4.d	6.4.2 6.4.2.2 6.4.3 6.5	●	○	○		Software Verification Cases and Procedures	11.13	①	①	②	
								Software Verification Results	11.14	②	②	②	
								Trace Data	11.21	①	①	②	

Note that this set of objectives clearly maps to 2X[4].1301 and 2X.1309 as well as 33.28.

- *...kind and design appropriate to its intended function;*
- *...designed to ensure that they perform their intended functions under any foreseeable operating condition.*

From Table 2, we can show that the two most expensive objectives in DO-178C are circled in Table 3 and are related to software robustness.

[4] Extracted from CFRs 25.1301 and 25.1309, but similar for Parts 23, 27, 29 and 33.

Table 3. The Two Most Expensive Objectives in DO-178C are Related to Robustness

	Objective		Activity	Applicability by Software Level				Output		Control Category by Software Level			
	Description	Ref	Ref	A	B	C	D	Data Item	Ref	A	B	C	D
1	Executable Object Code complies with high-level requirements.	6.4.a	6.4.2 6.4.2.1 6.4.3 6.5	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②
								Trace Data	11.21	①	①	②	②
2	Executable Object Code is robust with high-level requirements.	6.4.b	6.4.2 6.4.2.2 6.4.3 6.5	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②
								Trace Data	11.21	①	①	②	②
3	Executable Object Code complies with low-level requirements.	6.4.c	6.4.2 6.4.2.1 6.4.3 6.5	●	●	○		Software Verification Cases and Procedures	11.13	①	①	②	
								Software Verification Results	11.14	②	②	②	
								Trace Data	11.21	①	①	②	
4	Executable Object Code is robust with low-level requirements.	6.4.d	6.4.2 6.4.2.2 6.4.3 6.5	●	○	○		Software Verification Cases and Procedures	11.13	①	①	②	
								Software Verification Results	11.14	②	②	②	
								Trace Data	11.21	①	①	②	
5	Executable Object Code is compatible with target computer.	6.4.e	6.4.1.a 6.4.3.a	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②

Finally, there are two significant misperceptions of DO-178C:

1. Software validation is not addressed in the document though it is often claimed that DO-178C addresses software validation. *Requirements are validated at the system level (4754A) – software is verified to assure the implementation satisfies the requirements.*
2. There is not a significant cost differential for Level A vs. Level B vs. Level C. There is a substantial roll-off at Level D. (*Refer to the two red ovals in Table 3 – robustness [abnormal conditions – continued safe flight and landing under any foreseeable condition] is very expensive to deal with but is highly important for the safety of life considerations.*)

1.3.4 What to Do for X-57?

Probably not DO-178C in total. At least not Level A/B for the entire software package – at most only for logic dealing with hazardous thrust conditions at critical flight phases. (*Loss of thrust control and asymmetry monitors of some type? Perhaps some kind of SAE ARP 4754A architectural mitigation could be considered...*)

Note that AC 23.1309-1E allows "*catastrophic*" conditions to be mitigated with DO-178C Level C for Class I and II aircraft. However, the civil aviation authority may drive Electronic Control

Unit (ECU) software to at least DO-178C, Level B, as noted in AC 33.28-3, depending on specific hazards.

Bottom line, there may not be a DO-178C cost-benefit-safety[5] realization here, given no more than a few tens of hours total experimental flight time for something on the order of 30,000 lines of code[6].

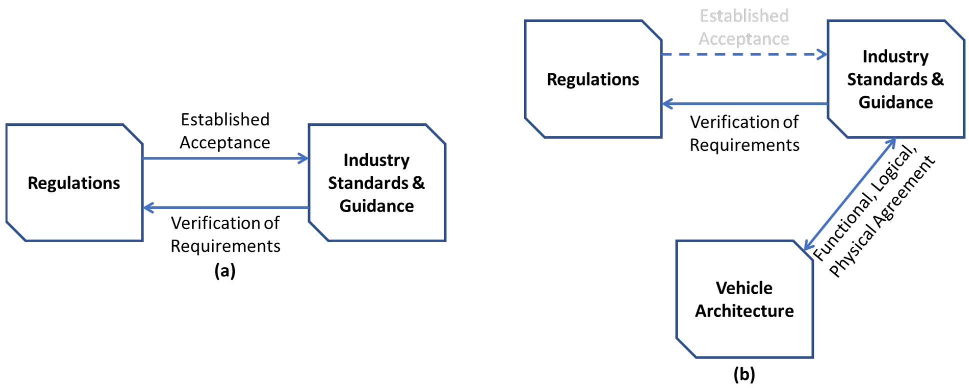
1.4 Model-Based Systems Engineering and Its Potential

Upon inspection of the findings of the AVP and companion results of this Compliance Checklist, it is evident that the airworthiness certification process involves a complex network of resources. These resources include, at a minimum, the documented regulatory requirements, ASTM standards, FAA Advisory Circulars, a documented vehicle architecture, and technical documentation on vehicle requirements, testing, and verification. The airworthiness community developed and successfully implemented a systems engineering process to manage this complexity. The method connects aspects of these various resources to guide the construction of the airworthiness plan. However, applying this traditional, document-driven approach to the X-57 vehicle has highlighted an element of inflexibility inherent to this process. Significant gaps emerge when the existing method is used on vehicles that incorporate novel technologies that are not explicitly included within airworthiness documents. Furthermore, to address these gaps under the current process, either existing documents must be modified or new documents created to address the underlying issue. While a tailor-made solution approach will address the particular gaps, the systemic issue which caused this gap will remain.

To better understand the emergence of these gaps, consider the relationships of the primary airworthiness plan elements shown in Figure 6. Once the certification basis is established, a suitable means of compliance must be identified. Where possible, means of compliance are identified from within a set of established means of compliance, consisting of existing industry standards or regulatory guidance. The set of established means of compliance can be considered as those which have an established acceptance by the regulatory body as appropriate methods of demonstrating verification of requirements. In cases the use of means of compliance with established acceptance is not appropriate, alternative standards or guidance may be leveraged by identifying those standards which demonstrate agreement with the proposed vehicle architecture.

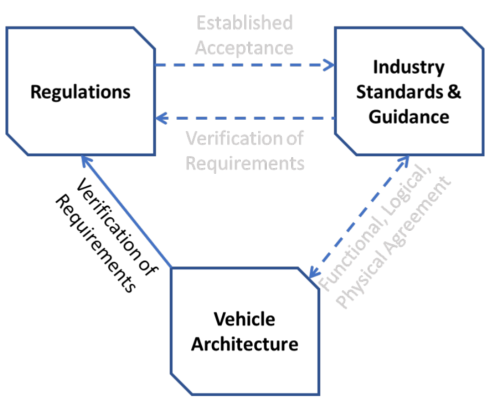
[5] The author makes no claims in terms of safety expertise but with a trained test pilot, flying in a restricted area, with planned maneuvers and recovery procedures, it would seem the operational scenarios are very different than many other civil platforms.
[6] Author's estimate for source lines of code (SLOC) based on a comparison to what would be a relatively simple turbine Electronic Control Unit (ECU).

Figure 6. Airworthiness Plan Elements and Relationships in Generating Means of Compliance With (a) Established Means of Compliance and (b) Alternative Means of Compliance



In instances where no standard or guidance is available as a means of compliance, as is the case for a subset of the X-57 airworthiness requirements, data from the vehicle architecture may be put forward as a verification of the requirements, as pictured in Figure 7. As outlined within this report, these data may include technical requirements of the vehicle and its systems and the test results, which provide verification that these requirements are satisfied. This process of means of compliance determination, progressing from the identification of external standards and data (Figure 6) to the utilization of internal vehicle data (Figure 7), was manually performed by the authors of this report. There is an opportunity, however, to envision this system engineering process of requirements identification and verification as a model-based process.

Figure 7. Utilization of Vehicle Architecture Data to Serve as Verification of Airworthiness Requirements



A model-based approach to airworthiness certification offers many potential benefits and improvements. Generally, through transformation to a model-based approach, the synthesis of the certification basis and means of compliance could transition from an exercise dominated by document management to one of model construction and architecture compatibility assessment. The containment of airworthiness regulations and standards within appropriately constructed models would improve the transparency of these resources. Indeed, this transparency would allow for additional clarity concerning the implications of potential changes or modifications at every stage of the airworthiness process. This insight could extend to industry members, allowing for increased traceability between vehicle architecture decisions and their interaction with interconnected elements of the airworthiness regulations. Furthermore, in instances wherein no existing standard or regulatory guidance is available, appropriate data elements within the vehicle model may be identified and connected with regulatory requirements as potential sources of verification.

This type of paradigm shift towards a model-based systems engineering formulation of the airworthiness certification process would entail the engagement of many stakeholders. Members of the research community, including academia and agencies like NASA, could be well suited to develop and formulate the methods, tools, and model templates that would be used to generate and deploy airworthiness models. Subject Matter Experts (SMEs) within regulatory agencies and standards bodies would be natural candidates to create and maintain models for regulations and standards. Once these models are generated and processes for their use are in place, other members of the industry could be engaged to develop industry standards and best practices for the generation of vehicle architecture models. Through this collaborative effort, it is envisioned that all stakeholders would reap the benefits of this model-based certification approach, thereby increasing the safety and efficiency of the aviation system through greater transparency, clarity, and connectivity.

1.5 Unique Aspects of the X-57 to a Certification Basis

In addition to the transformation of FAR 23 from prescriptive to regulation-by-objective (and codified in FAR 23, Amendment 64) and introduction of electric propulsion for FAR 33 (yet evolving under Subcommittee F39.05 on Design, Alteration, and Certification of Electric Propulsion Systems), these transformations can be managed, and have been addressed in several certification projects with manufacturers and civil aviation authorities. This report will show how the X-57 contributes to the existing body of knowledge.

Yet, the unique aspect of the X-57 is its DEP system. For the first time, a propulsion system will show how it acts as a high-lift device. Regulations and standards typically organized within conventional sets of boundaries will require reexamination. For example, how should a high-lift motor be treated as part of a bank of high-lift engines acting as a set of flaps-and-slats? Does a typically certified device under FAR 33 have to meet requirements in FAR 23, Subpart B, Flight?

ASTM Subcommittee F44.40 on Powerplant examines the changes needed in F3239-19, Standard Specification for Aircraft Electric Propulsion Systems, and ASTM F3316M-19, Standard Specification for Electrical Systems for Aircraft with Electric or Hybrid-Electric Propulsion, to assess the changes necessary to accommodate distributed propulsion systems. The X-57 will directly contribute to the changes needed in those two standards.

On 19 November 2020, the FAA issued the first set of special conditions for a 375 and 750 SHP electric propulsion unit (EPU) in the certification process by magniX[7]. Given that both electric motors are designed to accept propellers and rely on 2×3-phase inverter architecture for redundancy, this Special Condition applies to the X-57 in most respects.

[7] Federal Register, Docket ID FAA-2020-0894, *magniX USA, Inc., magni250 and magni500 Model Engines,* Notice of Proposed Special Conditions, Published November 19, 2020, with comments closing on December 21, 2020. See https://www.federalregister.gov/documents/2020/11/19/2020-23434/special-conditions-magnix-usa-inc-magni250-and-magni500-model-engines

The publication of the Special Conditions, and the continued development of the ASTM F3338-20, Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft, are unique opportunities for X-57 to leverage its technologies for their continued development.

2 Normal Category Airplanes

This section is organized by its Subparts to 14 CFR 23, including Subpart A, General, Subpart B, Flight, Subpart C, Structures, Subpart D, Design and Construction, Subpart E, Powerplant, Subpart F, Equipment, and Subpart G, Flightcrew Interface and Other Information. A discussion about Appendix A to Part 23, Instructions for Continued Airworthiness, is also summarized.

For each Subparts B through G in 14 CFR 23, a reference to the Means of Compliance from the ASTM F3264, Specification for Normal Category Aeroplanes Certification, is shown.

For each certification basis in each of the Subparts, an assessment was made and color-coded as to NASA's X-57 flight demonstrator to meet:

- Green: The means of compliance and methods of compliance associated with existing Standard Specifications and Standard Practices ASTM F39 and ASTM F44.
- Yellow: If such standards do not exist or are not appropriate, equivalent means and-or methods of compliance from appropriate FAA Advisory Circulars and other sources are suggested.
- Red: If no appropriate certification rule, means of compliance, and-or method of submission exists, highlight this omission and provide recommendations.
- Grey: If the certification basis does not apply to the X-57.

A summary of the distribution of the assessments of the certification basis by Subpart for Normal Category Aircraft is shown below.

	GREEN	YELLOW	RED	GREY
SUBPART A—GENERAL	71%	5%	0%	24%
SUBPART B—FLIGHT	43%	25%	0%	31%
SUBPART C—STRUCTURES	46%	45%	2%	7%
SUBPART D—DESIGN AND CONSTRUCTION	70%	21%	0%	9%
SUBPART E—POWERPLANT	10%	47%	1%	41%
SUBPART F—EQUIPMENT	48%	25%	0%	27%
SUBPART G—FLIGHT CREW INTERFACE AND OTHER INFORMATION	60%	33%	0%	7%

Generally, the application of standards based on the ASTM Standard F3264, Standard Specification for Normal Category Aeroplanes Certification, is still focused on an aircraft's usual configuration and does not even consider electric propulsion. For an aircraft like the X-57, this means that while some of the standards associated with 14 CFR Part 23 apply to the X-57, there is not an insignificant number of means of compliance that will need to be developed for aircraft like the X-57.

For each of the following sections, an introduction will describe the unique aspect of the X-57, and an overview of the applicability is described.

2.1 Subpart A, General

2.1.1 Unique Aspects of X-57 to This Subpart

The approach to Subpart A from a flight test perspective is to identify the certification level and performance level for the X-57 to properly apply the requirements of Subpart B. The X-57 is assumed to be a Certification Level 2 low-speed airplane with a VSO>45 Knots Calibrated Airspeed (KCAS) for regulatory compliance.

2.1.2 Certification Basis

Subpart A—General	**Note**
§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.	Applies to X-57
(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.	This definition applies to X-57. Note that aircraft damage may occur, but no mention is made of crew injuries/deaths. Assumption is that crew would sustain no life-threatening injuries. An important consideration when considering propulsive unit failures of both the high-lift and cruise systems.
§23.2005 Certification of normal category airplanes.	Applies to X-57
(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.	X-57 fits here
(b) Airplane certification levels are:	
(1) Level 1—for airplanes with a maximum seating configuration of 0 to 1 passengers.	NA
(2) Level 2—for airplanes with a maximum seating configuration of 2 to 6 passengers.	X-57 fits here
(3) Level 3—for airplanes with a maximum seating configuration of 7 to 9 passengers.	NA
(4) Level 4—for airplanes with a maximum seating configuration of 10 to 19 passengers.	NA
(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.	X-57 fits here
(2) High speed—for airplanes with a VNO or VMO > 250 KCAS or a MMO > 0.6.	NA
(d) Airplanes not certified for aerobatics may be used to perform any maneuver incident to normal flying, including—	X-57 fits here
(1) Stalls (except whip stalls); and	X-57 fits here
(2) Lazy eights, chandelles, and steep turns, in which the angle of bank is not more than 60 degrees.	X-57 fits here
(e) Airplanes certified for aerobatics may be used to perform maneuvers without limitations, other than those limitations established under subpart G of this part.	NA
§23.2010 Accepted means of compliance.	
(a) An applicant must comply with this part using a means of compliance, which may include consensus standards, accepted by the Administrator.	ASTM Consensus Standards will be used.
(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.	May be required if ASTM standards are inadequate.

2.2 Subpart B, Flight

2.2.1 Unique Aspects of X-57 to This Subpart

The approach to Subpart B is to identify applicable airworthiness requirement sub-paragraphs for the X-57 aircraft. Specific methods of compliance are described below in the context of applicable ASTM standards, and certification challenges are highlighted in the Note section of each requirement. The most significant challenge in showing compliance with flight requirements is adequately defining Cruise Motor (CM) and High Lift Propellers (HLP) operating concept and power settings for given configurations for which performance and handling qualities requirements must be demonstrated. The FAA must accept these concepts and power settings during the certification basis discussion of project development. Further, the FAA must also define and accept engine-out CM/HLP configurations during takeoff, climb, landing, and balked landing climb conditions to demonstrate performance and handling qualities requirements.

Airworthiness certification requires inflight field performance data and climb data development for normal and engine inoperative abnormal conditions. Stall speed and minimum control speed development are prerequisites to field performance testing. Stall speeds in various configurations and minimum control speed are integral to field performance test conditions and most stability, control, and handling qualities test cases. The operating concept of the HLP and CM systems must be well understood, and HLP/CM power settings and operational states during various phases of flight for airworthiness certification must be agreed to by the FAA.

The fundamental question is, should the HLP system be considered a high lift device like slats or a propulsive device that provides additional wing lift while also providing propulsive capability? Classification of the HLP system is key to the treatment of the system for certification purposes. Similarly, engine inoperative configurations for test cases used for field performance, stability, control and handling qualities testing must be well understood. HLP and CM configurations, power settings, and failure states for each test case must be defined and agreed to by FAA. Systems safety analyses and accompanying fault hazard analyses will help define likely abnormal configurations for test consideration.

2.2.2 Certification Basis

Subpart B—Flight	**Note**
Performance	
§23.2100 Weight and center of gravity.	Applies to X-57
(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.	Applies to X-57
(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	Applies to X-57
(2) Ambient atmospheric conditions within the operating envelope for levels 1 and 2 high-speed and levels 3 and 4 airplanes.	NA
(b) Unless otherwise prescribed, the applicant must develop the performance data required by this subpart for the following conditions:	Applies to X-57
(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.	

Subpart B—Flight	Note
(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.	Applies to X-57
(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.	Applies to X-57
§23.2110 Stall speed.	Applies to X-57
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—	Stall speed determination in all configs required including takeoff and landing engines-propellers and cruise engines-props only. Stall speeds are gathered during stall characteristics investigation used to determine the low-speed fight characteristics score, S_{LSC}. X-57 minimum S_{LSC} is 150.
(a) Idle or zero thrust for propulsion systems that are used primarily for thrust; and NOTE: CM system would be considered the primary thrust producing system. FAA consensus would be required.	CM/HLP use and power settings need to be defined for each config and agreed to by FAA. HLP on/off power off speeds required for approach and landing conditions.
(b) A nominal thrust for propulsion systems that are used for thrust, flight control, and/or high-lift systems. NOTE: Both (a) and (b) subparagraph power settings are required for stall speed determination. It is not either (a) or (b). HLP system would fall into the high-lift system category while the CM system would fall into the thrust producing category for those conditions where a "power-on" stall condition must be considered.	CM/HLP use and power settings need to be defined for takeoff and landing configs using both CM/HLP if HLM considered high lift systems. FAA consensus required.
§23.2115 Takeoff performance.	Applies to X-57
(a) The applicant must determine airplane takeoff performance accounting for—	Applies to X-57
(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 multi-engine airplanes, takeoff performance includes the determination of ground roll and initial climb distance to 50 feet (15 meters) above the takeoff surface.	Applies to X-57
(c) For levels 1, 2, and 3 high-speed multi-engine airplanes, and level 4 multi-engine airplanes, takeoff performance includes a determination the following distances after a sudden critical loss of thrust—	NA
(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:	
(a) With all engines operating and in the initial climb configuration—	X-57 Initial Climb Configuration? Both CM/HL?
(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	Applies to X-57
(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.	NA
(b) After a critical loss of thrust on multiengine airplanes—	Applies to X-57
(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); Assuming no ATI, what are CM/HLP motor states in a partial power condition? Is one CM inop and some combination of HLP motors inop the definition of an engine failure? SSA data will shape the partial power definition.	What defines critical loss of thrust in climb condition? Does X-57 meet OEI crashworthiness? What is the CM/HLP config?

Subpart B—Flight	**Note**
(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	NA
(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).	NA
(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).	Applies to X-57. Assume CM/HLP both operating? HLP Mode? RPM or Airspeed? Would a switch to RPM be required by the pilot?
§23.2125 Climb information.	Applies to X-57
(a) The applicant must determine climb performance at each weight, altitude, and ambient temperature within the operating limitations—	
(1) For all single-engine airplanes;	NA
(2) For levels 1 and 2 high-speed multi-engine airplanes and level 3 multi-engine airplanes, following a critical loss of thrust on takeoff in the initial climb configuration; and	NA
(3) For all multi-engine airplanes, during the enroute phase of flight with all engines operating and after a critical loss of thrust in the cruise configuration.	Applies to X-57. CM only?
(b) The applicant must determine the glide performance for single-engine airplanes after a complete loss of thrust.	NA
§23.2130 Landing.	
The applicant must determine the following, for standard temperatures at critical combinations of weight and altitude within the operational limits:	Applies to X-57
(a) The distance, starting from a height of 50 feet (15 meters) above the landing surface, required to land and come to a stop.	Applies to X-57
(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:	Applies to X-57
(1) Stall speed safety margin; and	
(2) Minimum control speeds. NOTE: CM/HLP failure states need to be defined and FAA accepted when developing test conditions for VMCA. With/without HLP would likely be required? SSA data required.	VMCA development requires definition of a critical loss of thrust. FAA agreement required.
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—	Applies to X-57
(1) At all loading conditions for which certification is requested;	Applies to X-57
(2) During all phases of flight;	Applies to X-57
(3) With likely reversible flight control or propulsion system failure; and	Applies to X-57. Propulsion failure state defined? Some combination of CM/HLP systems failures must be considered in accordance with the SSA.
(4) During configuration changes.	Applies to X-57. HLP stowing and unstowing operations. Malfunctions during stowing/unstowing?
(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.	Applies to X-57. HLP inop case using Vref with no HLP required?
(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 multi-engine airplanes, the applicant must determine VMC, if applicable, for the most critical configurations used in takeoff and landing operations.	Applies to X-57. Developing VMC with regard to agreed to CM/HLP failure states. FAA concurrence required

Subpart B—Flight	**Note**
(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.	NA
§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:	Applies to X-57
(1) For levels 1, 2, and 3 airplanes in cruise.	Applies to X-57
(2) For level 4 airplanes in normal operations.	NA
(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:	Applies to X-57
(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 multi-engine airplanes. NOTE: Critical loss of thrust needs to be defined and agreed to. Also other relevant CM/HLP abnormals/emergencies that may affect residual control forces.	Applies to X-57. Critical loss of thrust needs to be defined and agreed upon with FAA for each phase of flight in the normal operating envelope. Rudder forces may be excessive. A rudder bias system or other yaw augmentation system may be required.
§23.2145 Stability.	
(a) Airplanes not certified for aerobatics must—	Applies to X-57
(1) Have static longitudinal, lateral, and directional stability in normal operations;	A combination of CM/HLP depending on flight phase.
(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.	Applies to X-57
§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.	Applies to X-57. "Power-off" and "power-on" CM/HLP states defined and agreed upon.
(b) Single-engine airplanes, not certified for aerobatics, must not have a tendency to inadvertently depart controlled flight.	NA
(c) Levels 1 and 2 multi-engine airplanes, not certified for aerobatics, must not have a tendency to inadvertently depart controlled flight from thrust asymmetry after a critical loss of thrust.	Applies to X-57. Stall characteristics testing will require some asymmetric control inputs and possibly asymmetric propulsion application.
(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.	NA
(e) Spin characteristics in airplanes certified for aerobatics that includes spins must recover without exceeding limitations and may not result in unrecoverable spins—	NA
(1) With any typical use of the flight or engine power controls; or	
(2) Due to pilot disorientation or incapacitation.	

Subpart B—Flight	Note
§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.	Applies to X-57. Crosswind handling characteristics evaluated here. Engine inoperative cases evaluated here. Requires definition of likely failure combinations of CM/HLP.
§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.	Applies to X-57. CM to Vd. HLP flown to the max op speed for HLP.
(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.	NA
(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.	NA
(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—	NA
(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.	NA
(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):	NA
(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 calculated airspeed (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.	

2.2.3 ASTM F3264, Specification for Normal Category Aeroplanes Certification, §5. Flight

5. Flight	Notes
5.1 Weight/Mass and Centre of Gravity:	
5.1.1 F3082/F3082M – 17 Standard Specification for Weights and Center of Gravity of Aircraft	This standard is similar to Part 23 earlier amendments.
5.1.2 F3114 – 15 Standard Specification for Structures	Defer to Structures DER
5.2 Performance Data:	
5.2.1 F3179/F3179M – 18 Standard Specification for Performance of Aircraft	Performance data must be developed from sea level SL to 10000 mean sea level (MSL) and ISA+30 conditions.
5.3 Stall Speed:	

5. Flight	Notes
5.3.1 F3179/F3179M – 18 Standard Specification for Performance of Aircraft, Paragraph 5.	VSO and VS1 development required at max gross weight and least favorable center of gravity (CG)…usually aft. Power settings for CM/HLP defined and agreed to by FAA. Stall speeds gathered using stall characteristics flight test techniques described below. Stall speeds are gathered early in the test program as the speeds are used for development of other operating speeds.
5.4 Takeoff Performance:	
5.4.1 F3179/F3179M – 18 Standard Specification for Performance of Aircraft, Paragraph 6. Takeoff Speed Development, Para. 6.1, 6.1.1, 6.2, 6.2.2 Takeoff Field Performance Development, Para. 7.2	Takeoff speed development falls under paragraphs 6.1, 6.1.1, 6.2, 6.2.2. VS1 and VMC values required for takeoff speed development. CM/HLP conditions for takeoff, VMC, and stall testing defined and accepted by FAA acceptance. 65% CM and HLP in fixed mode likely acceptable by may limit WAT capability at high DA.
5.5 Climb Requirements:	
5.5.1 F3179/F3179M – 18 Standard Specification for Performance of Aircraft, Chapter 12	General requirements for critical loss of thrust definition, OGE requirement, and at speeds using in the cooling demonstration.
5.6 Climb Information:	
5.6.1 F3179/F3179M – 18 Standard Specification for Performance of Aircraft, Paragraph 13, AEO Takeoff Climb: Para. 13.2 Partial Loss of Thrust Climb: Para. 15.1. Required gradient depends on compliance with single engine crashworthiness standards F3083/F3083M. For non-compliance with crashworthiness standard: 1.5% gradient required at 5000' MSL For compliance with crashworthiness standard: Must be determined and can be a climb or descent gradient. Enroute Climb/Descent: Para 16.1, 16.2 AEO climb data developed at WAT conditions in the enroute config; Gear/Flaps/Retracted. High-lift motor config? Partial Loss of Thrust: Climb/descent gradient development at WAT conditions required. Critical loss of thrust configuration needs definition.	Para. 13.2 requires an 8.3% climb gradient at S_{LSC}. Maximum continuous power? CM at MCP or 65%? Reference is made to VMC and VS1 as previously discussed. Takeoff flap position is required. This implies use of HLP as well. Partial Power Loss Climb gradient requirement depends on single engine crashworthiness requirement compliance of F3083/F3083M. Para. 15.1 again, critical loss of thrust must be defined and agreed to by FAA. Para. 16.1, 16.2 Flaps retracted is stipulated here…implication for HLP? Enroute climb data development required for AEO and Partial Loss of Thrust conditions. Requires CM/HLP operating states for both cases.
5.7 Landing:	
5.7.1 F3179/F3179M – 18 Standard Specification for Performance of Aircraft. Paragraph 18.1, 19, 20.2	Landing speed development, landing distance development, and balked landing climb gradient development all required. VMC and VS1 speed development required along with thrust configuration for normal approach and landing, and balked landing climb.
5.8 Controllability:	
5.8.1 F3173/F3173M – 17 Standard Specification for Aircraft Handling Characteristics. General requirement.	General requirements discussed in Para. 4.1, 4.2. Smooth transitions, maximum control forces, and controllability/maneuverability in all phases of flight throughout the flight envelope are required.
5.9 Trim:	
5.9.1 F3173/F3173M – 17 Standard Specification for Aircraft Handling Characteristics, Paragraph 5.1, 5.2.1, 5.3.2, 5.4 (Critical Loss of Thrust)	

5. Flight	**Notes**
5.10 Stability:	
5.10.1 F3173/F3173M – 17 Standard Specification for Aircraft Handling Characteristics Para. 4.3.1, 4.3.2, 4.3.3.2, 4.3.4, 4.3.5.2, 4.4.1, .4.4.2, 4.4.3, 4.5 (except 4.5.4), 4.7, 4.8, 4.9, 6.1, 6.2, 6.3, 6.4 (except 6.4.2.1, 6.4.5), 6.5	Very similar to Part 23 [23-63] requirements. Longitudinal, lateral-directional stability and control testing requires many airspeed/configuration combinations. As discussed previously, power configuration for each stability and control case will require definition and FAA agreement. Critical loss of thrust condition test conditions are also listed, and power state will require definition as described above.
5.11 Stall Characteristics, Stall Warning, and Spins:	
5.11.1 F3180/F3180M – 18 Standard Specification for Low-Speed Flight Characteristics of Aircraft, Paragraph 4.1, 4.2, 4.3, 4.5, 4.7	Minimum S_{LSC} of 150 required. 4.2 stall characteristics must be a pass. Power-off thrust configuration needs definition along with appropriate power-on configuration. Airplane must be controllable up to the stall. Characteristics required very similar to part 23 [23-62]. Accelerated and turning stall characteristics also must be demonstrated. Similar to part 23 [23-62]. Stall warning score must be a 50 minimum which is usually satisfied by an aural stall warning system. S_{DCME}, departure characteristics score for multi-engine aircraft must be between 50 and 100. This is usually accomplished with either meeting loss of thrust climb gradient or having a VMC less than VS1. Safety-enhancing features may be used to increase the S_{LSC} score as described in Section 4.7.
5.12 Ground and Water Handling Characteristics:	
5.12.1 F3173/F3173M – 17 Standard Specification for Aircraft Handling Characteristics, Para. 7.1, 7.2	Water and unpaved surface operations omitted. Crosswind landing demonstration required. Could be a challenge for a high AR configuration. Partial loss of high-lift motor characteristics must be considered unless loss is extremely improbable.
5.13 Vibration, Buffeting, and High-Speed Characteristics:	
5.13.1 F3173/F3173M – 17 Standard Specification for Aircraft Handling Characteristics, paragraph 8.1	Flight to Vd required. Also required is a demonstration with high-lift motors operating at their max design speed. Configuration changes are also required for demonstration. This implies evaluating high-lift propeller stowing at maximum stowing speed permitted by design.
5.14 Performance and Flight Characteristics Requirements for Flight in Icing Conditions:	NA
5.14.1 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation Aircraft	NA
5.15 Operating Limitations:	
5.15.1 F3174/F3174M – 18 Standard Specification for Establishing Operating Limitations and Information for Aeroplanes.	Establishes airspeed limitations for various configurations along with minimum crew requirements and kinds of operation. Again, treatment of the high-lift motors as high lift devices will be a consideration when determining VFE or a VHLM (Max speed for high lift motor operation).

2.3 Subpart C, Structures

2.3.1 Unique Aspects of X-57 to This Subpart

Structural certification of an airframe to amendment 64 of FAR 23 will be very little changed from amendment 63.

There are a few items that warrant special consideration, especially early in the aircraft design phase, as knowledgeable design decisions can make certification easier, see items 1 through 5 below:

1. **Composite materials will need to consider effects of spilled battery acid. Current aircraft batteries are contained in a protective box, but this may not be practical for electric propulsion.**

FAR 23.2250, Design and construction principles, Amendment 64 requires substantiation that can be via 23.603, Materials and Workmanship, which requires:

The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must--
(1) Be established by experience or tests;
(2) Meet approved specifications that ensure their having the strength and other properties assumed in the design data; and
(3) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.
(b) Workmanship must be of a high standard.

2. **Amendment 64 adds a bird strike requirement not in amendment 63.**

§23.2320 Occupant physical environment.
(a) The applicant must design the airplane to—
(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.

3. **Requirements for flammable fluid fire protection no longer applicable.**
4. **Unsymmetrical loads due to engine failure could have many possible failure scenarios (multiple motors).**
5. **Rotor burst considerations could have many possible failure scenarios (multiple motors).**

Of these, items 1 and 2 are quite important and warrant consideration in the early design stages.

For example, most composite structure is currently comprised of carbon/epoxy which would likely be significantly damaged by battery acid. Materials that are resistant to battery acid would need to be developed or at least tested for structural properties.

Currently the X-57 experimental prototype wing drawings show a single spar which is quite efficient for the type of airfoil but not desirable for meeting the residual strength criteria of composite structure.

It is envisioned that Amendment 63 to FAR 23.573 will be the basis for FAA certification to Paragraph 23.2240 of FAR 23, amendment 64 (Structural Durability). Paragraph 23.573 (Amendment 63) has been REQUIRED for certification of composite structure and may be used for metallic structure.

FAR 23. 573 (1) (3) says " *The structure must be shown by residual strength tests, or analysis supported by residual strength tests, to be able to withstand critical limit flight loads, considered as ultimate loads, with the extent of detectable damage consistent with the results of the damage tolerance evaluations."*

The single load path primary structure is riskier than the multi-load path. Fundamentally, if anything goes wrong such as incorrect inspection, manufacturing flaw different from the test article, actual operational spectrum on a given aircraft different from the test program, any operational scenario outside the scope of the damage tolerance substantiation program, and a single load path structure fails the result is likely catastrophic.

While FAR 23.573 allows for certification of a single load path structure, this approach can add significantly to the in-service inspection and maintenance workloads and cost because subparagraph (a) (4) states:

"*The damage growth, between initial detectability and the value selected for residual strength demonstrations, factored to obtain inspection intervals, must allow development of an inspection program suitable for application by operation and maintenance personnel."*

A multiple load path design can assure that the required level of residual strength (limit load capability) is retained in the event of complete failure of any one element. Such a design reduces the risk of a catastrophic event and allows for a less-demanding inspection and maintenance program.

2.3.2 Certification Basis

Subpart C—Structures	**Notes- Reference FAR 23, AMNDT 63**
§23.2200 Structural design envelope.	§§ 23.321, Loads—General, paragraphs (b) and (c); 23.333, Flight envelope, para. (a), (b), and (d); 23.335, Design airspeeds; 23.337. Limit maneuvering load factors, para. (a) and (b); 23.343. Design fuel loads, paragraphs (a) and (b). (Not Applicable)
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:	23.333. Flight envelope, para. (a), (b), and (d);
(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—	§ 23.335, Design airspeeds;
(1) Be sufficiently greater than the stalling speed of the airplane to safeguard against loss of control in turbulent air; and	§ 23.335, Design airspeeds;
(2) Provide sufficient margin for the establishment of practical operational limiting airspeeds.	§ 23.335, Design airspeeds;
(b) Design maneuvering load factors not less than those, which service history shows, may occur within the structural design envelope.	§ 23.337 Limit maneuvering load factors, para. (a) and (b);
(c) Inertial properties including weight, center of gravity, and mass moments of inertia, accounting for—	§ 23.343. Design fuel loads, para. (a) and (b). (Not Applicable)
(1) Each critical weight from the airplane empty weight to the maximum weight; and	§ 23.523, Design weights and center of gravity positions;
(2) The weight and distribution of occupants, payload, and fuel.	

Subpart C—Structures	**Notes- Reference FAR 23, AMNDT 63**
(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.	§ 23.1309
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.	§ 23.1309 Para. (a)
Structural Loads	
§23.2210 Structural design loads.	§§ 23.301, Loads; 23.302, Canard or tandem wing configurations; (Not Applicable) 23.321 Flight Loads—General, paragraph (a); 23.331, Symmetrical flight conditions.
(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.	§§ 23.301, Loads;
(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.	§§ 23.301, Loads;
(b) The magnitude and distribution of the applicable structural design loads required by this section must be based on physical principles.	§§ 23.301, Loads;
§23.2215 Flight load conditions.	§ 23.333, Flight envelope, paragraph (c); 23.341, Gust loads factors; 23.347, Unsymmetrical flight conditions; 23.349, Rolling conditions; 23.351, Yawing conditions; 23.367, Unsymmetrical loads due to engine failure; 23.421, Balancing loads; 23.423, Maneuvering loads; 23.425, Gust loads; 23.427, Unsymmetrical loads; 23.441, Maneuvering loads; 23.443, Gust loads; 23.445, Outboard fins or winglets, paragraphs (b), (c), and (d).
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.	23.427, Gust loads;
(b) Symmetric and asymmetric maneuvers.	23.443, Maneuvering loads;
(c) Asymmetric thrust resulting from the failure of a powerplant unit.	23.367, Unsymmetrical loads due to engine failure;

Subpart C—Structures	**Notes- Reference FAR 23, AMNDT 63**
§23.2220 Ground and water load conditions.	§§ 23.471, Ground Loads—General; 23.473, Ground load conditions and assumptions; 23.477, Landing gear arrangement; 23.479, Level landing conditions; 23.481, Tail down landing conditions; 23.483, One-wheel landing conditions; 23.485, Side load conditions; 23.493, Braked roll conditions; 23.497, Supplementary conditions for tail wheels; 23.499, Supplementary conditions for nose wheels; 23.505, Supplementary conditions for skiplanes; 23.507, Jacking loads; 23.509, Towing loads; 23.511, Ground load; unsymmetrical loads on multiple-wheel units; 23.521, Water load conditions; 23.523, Design weights and center of gravity positions; 23.525, Application of loads; 23.527, Hull and main float load factors; 23.529, Hull and main float landing conditions; 23.531, Hull and main float takeoff condition; 23.533, Hull and main float bottom pressures; 23.535, Auxiliary float loads; 23.537, Seawing loads 23.753, Main float design.
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.	§ 23.471, Ground Loads—General
§23.2225 Component loading conditions.	§§ 23.345, High lift devices; 23.361, Engine torque; 23.363, Side load on engine mount; 23.365, Pressurized cabin loads; 23.371, Gyroscopic and aerodynamic loads; 23.373, Speed control devices; 23.391, Control surface loads; 23.393, Loads parallel to hinge line; 23.395, Control system loads; 23.397, Limit control forces and torques; 23.399, Dual control system; 23.405, Secondary control system; 23.407, Trim tab effects; 23.409, Tabs; 23.415, Ground gust conditions; 23.455, Ailerons; 23.459, Special devices.
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	23.371, Gyroscopic and aerodynamic loads;
(2) For non-reciprocating powerplants, sudden powerplant stoppage.	23.361, Engine torque;
(b) Each flight control and high-lift surface, their associated system and supporting structure resulting from—	23.391, Control surface loads 23.373, Special control devices
(1) The inertia of each surface and mass balance attachment;	23.391 Control surface loads
(2) Flight gusts and maneuvers;	23.391 Control surface loads
(3) Pilot or automated system inputs;	23.391 Control surface loads
(4) System induced conditions, including jamming and friction; and	23.391 Control surface loads
(5) Taxi, takeoff, and landing operations on the applicable surface, including downwind taxi and gusts occurring on the applicable surface.	23.391 Control surface loads
(c) A pressurized cabin resulting from the pressurization differential—	23.365, Pressurized cabin loads
(1) From zero up to the maximum relief pressure combined with gust and maneuver loads;	23.365, Pressurized cabin 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	23.365, Pressurized cabin loads
(3) At the maximum relief pressure multiplied by 1.33, omitting all other loads.	23.365, Pressurized cabin loads
§23.2230 Limit and ultimate loads.	§§ 23.301, Loads, paragraph (a); and 23.303,
The applicant must determine—	

Subpart C—Structures	**Notes- Reference** **FAR 23, AMNDT 63**
(a) The limit loads, which are equal to the structural design loads unless otherwise specified elsewhere in this part; and	§§ 23.301, Loads, paragraph (a); and 23.303,
(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.	§§ 23.301, Loads, paragraph (a); and 23.303,
Structural Performance	
§23.2235 Structural strength.	§§ 23.305, Strength and deformation; 23.307, Proof of structure.
The structure must support:	§§ 23.305, Strength and deformation; 23.307, Proof of structure.
(a) Limit loads without—	§§ 23.305, Strength and deformation; 23.307, Proof of structure.
(1) Interference with the safe operation of the airplane; and	§§ 23.305, Strength and deformation; 23.307, Proof of structure.
(2) Detrimental permanent deformation.	§§ 23.305, Strength and deformation; 23.307, Proof of structure.
(b) Ultimate loads.	§§ 23.305, Strength and deformation; 23.307, Proof of structure.
§23.2240 Structural durability.	Analysis and testing of the Single Spar Design for Mod III-IV wing: §§ 23.365(e), Pressurized cabin loads; 23.571, Metallic pressurized cabin structures; 23.572, Metallic wing, empennage, and associated structures; 23.573, Damage tolerance and fatigue evaluation of structure; 23.575, Inspections and other procedures 23.627, Fatigue strength.
(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.	23.575, Inspections and other procedures
(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.	23.575, Inspections and other procedures
(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.	23.627, Fatigue strength.
(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.	23.627, Fatigue strength.
(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.	§ 23.901(f), 23.903(b)(l), Rotor burst
§23.2245 Aeroelasticity.	§§ 23.629, Flutter; 23.677, Trim systems, para. (c); 23.687, Spring devices,
(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 C—Structures	**Notes- Reference FAR 23, AMNDT 63**
Design	
§23.2250 Design and construction principles.	§§ 23.601, Design and Construction—General; 23.603, Materials and workmanship, para. (b); 23.671, Control Systems—General, paragraph (a); 23.683, Operation tests; 23.685, Control system details; 23.687, Spring devices, in part 23.689, Cable systems.
(a) The applicant must design each part, article, and assembly for the expected operating conditions of the airplane.	§§ 23.601, Design and Construction—General
(b) Design data must adequately define the part, article, or assembly configuration, its design features, and any materials and processes used.	§§ 23.601, Design and Construction—General
(c) The applicant must determine the suitability of each design detail and part having an important bearing on safety in operations.	§§ 23.601, Design and Construction—General
(d) The control system must be free from jamming, excessive friction, and excessive deflection when the airplane is subjected to expected limit airloads.	23.671, Control Systems—General, paragraph (a);
(e) Doors, canopies, and exits must be protected against inadvertent opening in flight, unless shown to create no hazard when opened in flight.	§§ 23.601, Design and Construction—General
§23.2255 Protection of structure.	§§ 23.607, Fasteners; 23.609, Protection of structure; 23.611, Accessibility.
(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.	§§ 23.607, Fasteners;
(b) Each part of the airplane must have adequate provisions for ventilation and drainage.	§§ 23.601, Design and Construction—General
(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.	§§ 23.605, Fabrication methods 23.613, Material strength properties and design values.
(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.	23.613, Material strength properties and design values.
(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.	§§ 23.605, Fabrication methods
(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.	§§ 23.601, Design and Construction—General
(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.	23.613, Material strength properties and design values.
(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.	23.613, Material strength properties and design values.
(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.	23.613, Material strength properties and design values.
(g) An applicant may use other material design values if approved by the Administrator.	
§23.2265 Special factors of safety.	§§ 23.619, Special factors; 23.621, Casting factors; 23.623, Bearing factors; 23.625, Fitting factors; 23.657, Hinges; 23.681(b), Limit load static test (in part); 23.693, Joints.

Subpart C—Structures	**Notes- Reference** **FAR 23, AMNDT 63**
(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—	*High-Lift Motor-Propeller during stowing-unstowing of HLMP*
(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.	§§ 23.561, Emergency Landing Conditions—General; 23.562, Emergency landing dynamic conditions; 23.785, Seats, berths, litters, safety belts, and shoulder harnesses; 23.787, Baggage and cargo compartments.
(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	§§ 23.561, Emergency Landing Conditions—General
(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.	§§ 23.561, Emergency Landing Conditions—General
(b) The emergency landing conditions specified in paragraph (a)(1) and (a)(2) of this section, must—	23.562, Emergency landing dynamic conditions
(1) Include dynamic conditions that are likely to occur in an emergency landing; and	23.562, Emergency landing dynamic conditions
(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.	23.562, Emergency landing dynamic conditions
(c) The airplane must provide protection for all occupants, accounting for likely flight, ground, and emergency landing conditions.	§§ 23.561, Emergency Landing
(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.	23.785, Seats, berths, litters, safety belts, and shoulder harnesses;
(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;	23.787, Baggage and cargo compartments.
(2) Have a means to prevent the contents of the compartment from becoming a hazard by impacting occupants or shifting; and	23.787, Baggage and cargo compartments.
(3) Protect any controls, wiring, lines, equipment, or accessories whose damage or failure would affect safe operations.	23.787, Baggage and cargo compartments.

2.3.3 ASTM F3264, Specification for Normal Category Aeroplanes Certification, §6. Structures

6. Structures	**Notes**
6.1 Structural Design Envelope:	
6.1.1 F3116/F3116M – 18 Standard Specification for Design Loads and Conditions	

6. Structures	**Notes**
6.2 Interaction of Systems and Structure	
6.3 Structural Design Loads:	
6.3.1 F3116/F3116M – 18 Standard Specification for Design Loads and Conditions	
6.4 Flight Load Conditions:	
6.4.1 F3116/F3116M – 18 Standard Specification for Design Loads and Conditions	
6.5 Ground and Water Load Conditions:	
6.5.1 F3116/F3116M – 18 Standard Specification for Design Loads and Conditions	
6.5.1.1 F3331 – 18 Standard Practice for Aircraft Water Loads	
6.6 Component Loading Conditions:	
6.6.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
6.6.1.1 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
6.6.2 F3116/F3116M – 18 Standard Specification for Design Loads and Conditions	
6.7 Limit and Ultimate Loads:	
6.7.1 F3114 – 15 Standard Specification for Structures	
6.8 Structural Strength:	
6.8.1 F3114 – 15 Standard Specification for Structures	
6.9 Structural Durability:	
6.9.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
6.9.2 F3115/F3115M – 15 Standard Specification for Structural Durability for Small Aeroplanes	
6.10 Aeroelasticity:	
6.10.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
6.10.2 F3093/F3093M – 15 Standard Specification for Aeroelasticity Requirements	
6.11 Design and Construction Principles:	
6.11.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
6.11.1.1 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
6.11.2 F3114 – 15 Standard Specification for Structures	
6.12 Protection of Structure:	
6.12.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
6.12.1.1 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
6.12.2 F3114 – 15 Standard Specification for Structures	
6.12.3 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
6.13 Materials and Processes:	
6.13.1 F3114 – 15 Standard Specification for Structures	
6.14 Special Factors of Safety:	
6.14.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
6.14.2 F3114 – 15 Standard Specification for Structures	
6.15 Emergency Conditions:	
6.15.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
6.15.1.1 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
6.15.2 F3083/F3083M – 16 Standard Specification for Emergency Conditions, Occupant Safety and Accommodations	

2.4 Subpart D, Design and Construction

2.4.1 Unique Aspects of X-57 to This Subpart

The approach to Subpart D is similar to the approach used in Subpart C, which is to base it on compliance per 14 CFAR 23, Amendment 63.

2.4.2 Certification Basis

Subpart D—Design and Construction	**Notes**
§23.2300 Flight control systems.	§23.700
(a) The applicant must design airplane flight control systems to:	
(1) Operate easily, smoothly, and positively enough to allow proper performance of their functions.	§§ 23.677, Trim systems, paragraphs (a), (b), and (d);
(2) Protect against likely hazards.	§§ 23.677, Trim systems, paragraphs (a),
(b) The applicant must design trim systems, if installed, to:	
(1) Protect against inadvertent, incorrect, or abrupt trim operation.	§§ 23.677, Trim systems, paragraphs (a),
(2) Provide a means to indicate—	
(i) The direction of trim control movement relative to airplane motion;	§§ 23.677, Trim systems, paragraphs (a),
(ii) The trim position with respect to the trim range;	§§ 23.677, Trim systems, paragraphs (a),
(iii) The neutral position for lateral and directional trim; and	§§ 23.677, Trim systems, paragraphs (a),
(iv) The range for takeoff for all applicant requested center of gravity ranges and configurations.	§§ 23.677, Trim systems, paragraphs (a),
§23.2305 Landing gear systems.	§ 23.2305 captures the safety intent of current §§ 23.729, Landing gear extension and retraction system, paragraphs (a), (b), (c), and (e); 23.731, Wheels; 23.733, Tires, paragraph (a); 23.735, Brakes, paragraphs (a), (b), and (e); 23.737, Skis.
(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).	§§ 23.729, Landing gear extension and retraction system, paragraphs (c)
(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.	23.735, Brakes, paragraphs (a), (b), and (e);
(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	23.729 (2) (b)
(2) An alternative means available to bring the landing gear in the landing position when a non-deployed system position would be a hazard.	23.729 (2) (c)
§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	23.751, main float buoyancy
(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.	23.23.755, hulls 23.757, Auxiliary floats
Occupant System Design Protection	
§23.2315 Means of egress and emergency exits.	§§ 23.783, Doors, paragraphs (a), (b), (c), and (d); 23.791, 23.803, Emergency evacuation, paragraph (a); 23.805, Flightcrew emergency exits; 23.807, Emergency exits

Subpart D—Design and Construction	**Notes**
(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.	23.803, Emergency evacuation,
(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.	23.807, Emergency exits
(3) Have easy access to emergency exits when present.	23.807, Emergency exits
(b) Airplanes approved for aerobatics must have a means to egress the airplane in flight.	
§23.2320 Occupant physical environment.	§§ 23.771, Pilot compartment, paragraphs (b) and (c); 23.775, Windshields and windows, paragraphs (a), (b), (c), (d), and (h); 23.831, Ventilation; 23.841, Pressurized cabins, paragraphs (a), (b)(6), (c) and (d); 23.843, Pressurization tests; 23.1461, Equipment containing high energy rotors
(a) The applicant must design the airplane to—	
(1) Allow clear communication between the flightcrew and passengers;	§§ 23.771, Pilot compartment, paragraphs (b) and (c);
(2) Protect the pilot and flight controls from propellers; and	23.1461, Equipment containing high energy rotors
(3) Protect the occupants from serious injury due to damage to windshields, windows, and canopies.	23.775, Windshields and windows, paragraphs (a), (b), (c), (d), and (h);
(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.	Not currently in Part 23.
(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.	23.831, Ventilation;
(d) If a pressurization system is installed in the airplane, it must be designed to protect against—	Pressurized cabins, paragraphs (a), (b)(6), (c) and (d);
(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—	23.853, Passenger and crew compartment
(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—	

Subpart D—Design and Construction	Notes
(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.	23.859, Combustion heater fire protection, paragraph (a);
(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.	§§ 23.851, Fire extinguishers, paragraphs (a) and (b)
(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.	§§ 23.851, Fire extinguishers, paragraphs (a) and (b)
(g) Each area where flammable fluids or vapors might escape by leakage of a fluid system must—	23.863, Flammable fluid fire protection, paragraphs (a) and (d)
(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.	23.859, Combustion heater fire protection, paragraph (a);
§23.2330 Fire protection in designated fire zones and adjacent areas.	§ 23.865, Fire protection of flight controls, engine mounts, and other flight structure and § 23.1359(b), Electrical system fire protection
(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.	§ 23.865, Fire protection of flight controls, engine mounts, and other flight structure
(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.	23.1359, Electrical system fire protection, paragraph (c); 23.1365, Electric cables and equipment, paragraph (b); 23.1383, Taxi and landing lights, paragraph (d); 23.1385, Position light system installation, paragraph (d)
§23.2335 Lightning protection.	Not applicable to X-57
The airplane must be protected against catastrophic effects from lightning.	

2.4.3 ASTM F3264, Specification for Normal Category Aeroplanes Certification, §7. Design and Construction

7. Design and Construction	Notes
7.1 Flight Control Systems:	
7.1.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.1.1.1 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
7.1.2 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
7.2 Landing Gear Systems:	
7.2.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.3 Buoyancy for Seaplanes and Amphibians:	

7. Design and Construction	Notes
7.3.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.4 Means of Egress and Emergency Exits:	
7.4.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.4.2 F3083/F3083M – 16 Standard Specification for Emergency Conditions, Occupant Safety and Accommodations	
7.5 Occupant Physical Environment:	
7.5.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.5.1.1 F3227/F3227M – 17 Standard Specification for Environmental Systems in Small Aircraft	
7.5.2 F3083/F3083M – 16 Standard Specification for Emergency Conditions, Occupant Safety and Accommodations	
7.5.3 F3114 – 15 Standard Specification for Structures	
7.5.4 F3117 – 18b Standard Specification for Crew Interface in Aircraft	
7.6 Fire Protection:	
7.6.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.6.1.1 F3231/F3231M – 17 Standard Specification for Electrical Systems in Small Aircraft	
7.6.1.2 F3234/F3234M – 17 Standard Specification for Exterior Lighting in Small Aircraft	
7.6.2 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
7.6.3 F3083/F3083M – 16 Standard Specification for Emergency Conditions, Occupant Safety and Accommodations	
7.7 Fire Protection in Designated Fire Zones and Adjacent Areas:	
7.7.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.7.1.1 F3231/F3231M – 17 Standard Specification for Electrical Systems in Small Aircraft	
7.7.2 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
7.7.3 F3114 – 15 Standard Specification for Structures	
7.8 Lightning Protection:	
7.8.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
7.9 Design and Construction Information	

2.5 Subpart E, Powerplant

2.5.1 Unique Aspects of X-57 to This Subpart

FAA certified aircraft have traditionally relied on 14 CFR Part 23, Part 33, and Part 36 for those airworthiness requirements, constituting the certification basis for a new design aircraft, including powerplant aspects. These FAA regulatory requirements have been shown to amply serve general aviation, as evident from the well-established safety record for those aircraft, engines, and propellers certified to 14 CFR Parts 23, 33, and 36, including the related regulations for rotary wing aircraft. The recent evolution of ASTM standards under the F44 Standards Provision provides an alternative means of validating the airworthiness of a general aviation aircraft and its suitability for introduction to commercial usage. Most notably is the evolving ASTM Standard F3338 Specification for Design of Electric Propulsion Units for General Aviation Aircraft. Foremost, airworthiness and safety remain the guiding principle regardless of the standard used to certify the acceptability of the aviation product.

As background, the 14 CFR Part 23 regulatory requirements view the air vehicle powerplant as encompassing all those components and subsystems necessary to provide the propulsive means.

Thus, the FAA regulatory basis recognizes the powerplant as including not only the primary engine or means of providing propulsion but additionally engine mounting, propeller, engine controls, cooling provisions, powerplant controls, and instrumentation, and in the case of an electric propulsion system the energy storage devices and associated controls.

The NASA X-57 distributed powerplant architecture represents a novel approach to propulsion but in some respects has its heritage in the aircraft designs of yesteryears which employed multiple powerplants, each driving a propeller, conveniently arranged on the leading edge of each wing. Integrating multiple state of the art electric propulsive units driving unique high-lift propellers with electrical energy furnished by state of the art battery units and associated software-based controls represents a precedent-setting innovative design for an electric-powered multi-engine general aviation aircraft. Currently, the aggregate of the Part 23 requirements does not include specific provisions for electric propulsion, although the scope and general requirements remain applicable. Accordingly, the certification basis defined for the X-57 powerplant must consist of not only the 14 CFR Part 23 requirements but also the applicability of the evolving and maturing ASTM Standards for electric propulsion, including identification of prescriptive requirements for where gaps may exist.

Reflecting the FAA Part 23 definition of powerplant, the X-57 powerplant certification basis is integrally linked and dependent upon the airworthiness assessments in other aircraft areas. For example, propulsion system safety analysis has become a groundbreaking endeavor for the distributed propulsion system.

The proposed powerplant certification basis for the NASA X-57 distributed propulsion system is aligned with the latest 14 CFR Part 23, Subpart E requirements, Amendment 64. Whereas Subpart E, as currently drafted, does not explicitly address electric or hybrid propulsion, the proposed certification basis for the X-57 is expanded to include the applicable requirements of ASTM Standards F3264 §8, F3316, and F3239, which delineate the requirements for design and installation of an electrical propulsion system including components and supporting equipment.

Also included are relevant requirements from prior Part 23 Subpart E amendments where an assessment has identified gaps in requirements essential to ensuring the airworthiness of electric propulsion.

A cross-reference with the applicable requirements of the latest ASTM F44 standards is included in the certification basis for the distributed powerplant architecture.

2.5.2 Certification Basis

Subpart E—Powerplant	**Notes**
§23.2400 Powerplant installation.	Applies to X-57.
(a) For the purpose of this subpart, the airplane powerplant installation must include each component necessary for propulsion, which affects propulsion safety, or provides auxiliary power to the airplane.	Applies to X-57. 1) Distributed electrical propulsion requires system level assessment. See also 23.2410

Subpart E—Powerplant	Notes
(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 the Administrator has 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.	Applies to X-57. 1) EPU type certificate requirements equivalent to Part 33 are yet to be defined. 2) Distributed electrical propulsion with multiple engines requires airworthiness assessment at both the engine and component level in addition to assessment at the system level of the integrated multiple engine propulsion system.
(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.	Applies to X-57. This section is fundamentally applicable to a distributed electrical propulsion system. F3062 Sect 4.2.1 requirements are an important cornerstone requirement for installation.
(d) Hazardous accumulations of fluids, vapors, or gases must be isolated from the airplane and personnel compartments, and be safely contained or discharged.	Applies to X-57. This section is fundamentally applicable to a distributed electrical propulsion system. See also 23.2320(c) Occupant Physical Environment.
(e) Powerplant components must comply with their component limitations and installation instructions or be shown not to create a hazard.	Applies to X-57. This section is fundamentally applicable to a distributed electrical propulsion system.
§23.2405 Automatic power or thrust control systems.	Applies to X-57. Primary cert basis fundamentally applicable to a distributed electrical propulsion system.
(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.	Applies to X-57. Primary cert basis fundamentally applicable to a distributed electrical propulsion 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.	Applies to X-57. Primary cert basis fundamentally applicable to a distributed electrical propulsion system.
(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.	Applies to X-57. Primary cert basis fundamentally applicable to a distributed electrical propulsion system.

Subpart E—Powerplant	Notes
(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.	Applies to X-57. Primary cert basis fundamentally applicable to a distributed electrical propulsion system.
§23.2410 Powerplant installation hazard assessment. The applicant must 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.	Applies to X-57. Fundamentally applicable to a distributed electrical propulsion system.
§23.2415 Powerplant ice protection.	*Not applicable to X-57*
(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.	
§23.2430 Fuel systems.	*Not applicable to X-57, but may be considered as an analog for Energy Storage System*
(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;	

Subpart E—Powerplant	Notes
(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.	*Not applicable to X-57*
(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.	
§23.2440 Powerplant fire protection.	See F3239 §7.3.1.1 for definition of ESS, EPU fire zone
(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.	See F3239 §7.3.1.1 for definition of ESS, EPU fire 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 fireproof 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.	

2.5.3 ASTM F3316 Standard Specification for Aircraft with Electric or Hybrid-Electric Propulsion

ASTM F3316 Standard Specification for Aircraft With Electric or Hybrid Electric	Notes
3. Terminology	

ASTM F3316 Standard Specification for Aircraft With Electric or Hybrid Electric	**Notes**
3.1 Terminology specific to this specification is provided below. For general terminology, refer to Terminology F3060. 3.2 Definitions of Terms Specific to This Standard: 3.2.1 aircraft type code, n—an Aircraft Type Code (ATC) is defined by considering both the technical considerations regarding the design of the aircraft and the airworthiness level established based upon risk-based criteria; the method of defining an ATC applicable to this specification is defined in Specification F3061/F3061M. 3.2.2 **continued safe flight and landing**, n—continued safe flight and landing as applicable to this specification is defined in Specification F3061/F3061M. ***3.2.3 Battery Management System (BMS)***—a battery management system is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its Safe Operating Area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it or balancing it, or both. ***3.2.4 Electric Propulsion System (EPS)***—installation that includes at least one EPU and hardware required to produce propulsive thrust. Multiple EPUs may be in different arrangements such as serial or parallel or a combination of the two. ***3.2.5 Electric Propulsion Unit (EPU)***—the EPU shall as a minimum consist of the electric motor, associated controllers disconnects and wiring, motor generator, and monitoring gauges and meters. **3.2.6** ***Energy Storage System (ESS)***—any manner that stores some form of energy that can be drawn upon at a later time to provide energy for propulsion. Typical energy storage devices include but are not limited to: batteries, fuel cells, or capacitors. ***3.3 Abbreviations:*** 3.3.1 *BMS*—Battery Management System 3.3.2 *EPS*—Electric Propulsion System 3.3.3 *EPU*—Electric Propulsion Unit 3.3.4 *ESS*—Energy Storage System	*F3316 definitions for terminology are applicable across spectrum of certification basis*
4.1 Power Source Capacity & Distribution	
4.1.1 Each installation whose functioning is required for type certification or under operating rules and that requires a power supply is an "essential load" on the power supply. The power sources and the system must be able to supply the power loads specified in 4.1.1.1 – 4.1.1.3 in probable operating combinations and for probable durations. The power loads may be assumed to be reduced under a monitoring procedure consistent with safety in the kinds of operation authorized.	
4.1.1.1 The power sources and the electrical distribution system, when functioning normally, must be able to support all connected loads.	
4.1.1.2 The power sources and the electrical distribution system must be able to support all essential loads after the failure of any one ESS or primary electrical power source. An EPU designed to be connected to only one ESS is excluded from this requirement.	
4.1.1.3 The power sources and the electrical distribution system must be able to support all essential loads for which an alternate source of power is required, after any failure or malfunction in any one ESS, any one power supply system, any one distribution system, or any other utilization system. An EPU designed to be connected to only one ESS is excluded from this requirement.	
4.1.2 The power source and the electrical distribution system used to satisfy the probable duration requirement of 4.1.1 is required to provide electrical power to those loads that are essential to continued safe flight and landing including noncontinuous essential loads with enough capacity to meet the requirements of either 4.1.2.1, 4.1.2.2, or 4.1.2.3 as appropriate per Table 1.	
4.1.2.1 The time needed to complete the function required, for continued safe flight and landing.	
4.1.2.2 A time period of at least 30 minutes which includes the time to recognize the loss of primary power and to take appropriate load shedding action.	
4.1.2.3 A time period of at least 60 minutes which includes the time to recognize the loss of primary power and to take appropriate load shedding action.	
4.1.3 The electrical capacity duration requirement of 4.1.2 shall be demonstrated by test or analysis including all loads essential to continued safe flight.	
4.2 Electrical Systems and Equipment	

ASTM F3316 Standard Specification for Aircraft With Electric or Hybrid Electric	**Notes**
4.2.1 Electric power sources, their transmission cables, and their associated control and protective devices, must be able to furnish the required power at the proper voltage and frequency, if applicable to each load circuit essential for safe operation and maintained within the limits for which the equipment is designed during any probable operating conditions. 4.2.2 Compliance with 4.2.1 must be shown by an electrical load analysis or by electrical measurements that account for the electrical loads applied to the electrical system in probable combinations and for probable durations. 4.2.3 Each electrical system, when installed, must be free from hazards in itself, in its method of operation, and in its effects on other parts of the aeroplane. 4.2.4 Each electrical system, when installed, must be protected from fuel, oil, water, other detrimental substances, and mechanical damage. 4.2.5 Each electrical system, when installed, must be designed so that the risk of electrical shock to crew, passengers, and ground personnel is reduced to a minimum. 4.2.6 Electric power sources must function properly when connected in combination or independently. 4.2.7 No failure or malfunction of any electric power source may impair the ability of any remaining source to supply load circuits essential for safe operation. 4.2.8 Each electrical system must be designed so that essential load circuits can be supplied in the event of reasonably probable faults or open circuits including faults in heavy current carrying cables. 4.2.9 A means must be accessible in flight to the appropriate flight crewmembers for the individual and rapid disconnection of the electrical power sources from the distribution system which includes the distribution busses, their associated feeders, each control device, and each protective device. 4.2.10 If any particular system or item of equipment requires two independent sources of electrical power, their electrical energy supply must be ensured by means such as duplicate electrical equipment, throw over switching, or by the use of multichannel or loop circuits separately routed. 4.2.11 There must be a means to give immediate warning to the appropriate flight crew members of a failure of any primary electrical power source. 4.2.12 Each electrical power source must have a means to prevent damage to the electrical system, or to equipment supplied by the electrical system that could result if the power source provided electrical power outside the qualified limits that would damage the electrical system or equipment. 4.2.13 A means must exist to indicate to appropriate flight crewmembers the electric power system quantities essential for safe operation. 4.2.14 If provisions are made for connecting external power to the aeroplane, a means must be provided to ensure that no external power supply having an over voltage, an under voltage, a reverse polarity, or a reverse phase sequence, can supply power to the aeroplane electrical system. 4.2.15 If provisions are made for connecting **external power** to the aeroplane, the external power connection must be located so that its use will minimize the hazard to the aeroplane and ground personnel. 4.2.16 If provisions are made for connecting external power to the aeroplane to charge the aeroplane battery, a means must be provided to automatically disconnect the external power in the event of a malfunction of the aeroplane battery or battery management system. 4.2.17 If equipped with a combustion engine that is part of the Hybrid-Electric Propulsion System, electrical equipment must be so designed and installed that in the event of a fire in the combustion engine compartment, during which the surface of the firewall adjacent to the fire is heated to 1095°C [2000°F] for five minutes or to a lesser temperature substantiated by the applicant, the equipment essential to continued safe operation and located behind the firewall will function satisfactorily and will not create an additional fire hazard.	Should not this requirement apply to an ESS?
4.3 Circuit Protective Devices	
4.4 Master Switch Arrangement 4.5 Switches	
4.6 Electrical Cables and Equipment	
4.7 Electrical System Fire Protection	See also F3061 and F3066; align with §23.2440

ASTM F3316 Standard Specification for Aircraft With Electric or Hybrid Electric	**Notes**
4.8 Electronic Equipment	
4.9 Storage Battery Design and Installation	See also F3235

2.5.4 ASTM F3239 Standard Specification for Aircraft Electric Propulsion Systems

ASTM F3239 Standard Specification for Aircraft Electric Propulsion Systems	**Notes**
3. Terminology	
3.2 Definitions: 3.2.1 capacity, n—total amount between minimum and maximum condition (for example, empty and full). 3.2.2 electric propulsion system (EPS), n—the installation of one or more electric propulsion units including each component that is necessary for propulsion or affects the propulsive safety. 3.2.3 electric propulsion unit (EPU), n—a minimum EPU is comprised of the electric motor, associated electronic controllers, disconnects, wiring, and sensors. 3.2.3.1 Discussion—The EPU is an aircraft engine in accordance with 14 CFR Part 1.1 and CS-Definitions. 3.2.4 energy distribution system, n—a system that provides energy for propulsion from the energy storage systems to the propulsive units. 3.2.4.1 Discussion—The energy distribution system is considered equivalent to the fuel system on liquid hydrocarbon based powerplants. 3.2.5 energy storage system (ESS), n—a source (component or system) that stores and provides energy that can be drawn upon for propulsion. 3.2.5.1 Discussion—Typical energy storage systems include but are not limited to batteries, fuel cell systems or capacitors and their integrated management systems, if installed. The energy storage system is considered equivalent to a fuel tank on liquid hydrocarbon based powerplants. 3.2.6 quantity, n—amount available at the time of measurement. 3.2.7 usable energy capacity, n—minimum capacity of an energy storage system between the defined fully charged and the minimum charge state which can be drawn upon at any rate up to maximum rated power of this energy storage system under any likely operating condition.	***F3239 definitions of EPS & EPU are applicable across the spectrum of certification basis*** ***Broad equivalency to powerplant fuel system & fuel tank; however, certification basis for EPU and ESS is best prescribed by applicable ASTM Standards***
4. Powerplant Installation:	
5. Energy Distribution Systems	See also F3063 and F3316
5.2 Independence	
5.2.1 For aeroplanes with multiple EPUs, the energy distribution system shall be designed so that, in at least one system configuration, the failure of any one component will not result in the loss of power of more than one EPU or require immediate action by the pilot to prevent the loss of power of more than one EPU. ***NOTE 2—Refer to AC23-16 for guidance on the independence of energy distribution systems.***	***See also Subpart E Part 23.2430a.1***
5.3 Energy Storage System	
5.3.2 Installation	
5.3.3 Compartments	See also F3114 and F3316
5.3.3.1 Each energy storage system shall be ventilated and drained as necessary to prevent accumulation of hazardous, flammable, or corrosive fluids or vapors. 5.3.3.2 Each energy storage system shall be isolated from personnel compartments by an enclosure that is vented and drained to the exterior of the aeroplane. 5.3.3.3 Any enclosure required by 5.3.3.2 shall sustain any personnel compartment pressurization loads without permanent deformation or failure under the conditions defined in Specifications F3116/F3116M and F3114/F3114M. 5.3.3.4 For energy storage systems in compartments adjacent to fire zones there shall be sufficient clearance or insulation between the compartment and the firewall to prevent ignition or malfunction of the energy storage system as a result of fire in the fire zone.	***§7.3.1.1 of F3239 states – "The EPU or ESS section is a designated fire zone if a fire hazard exists"***
5.3.4 Energy Capacity	
5.3.5 Charging System	
5.3.6 Pilot-replaceable Energy Storage System 6. Control and Installation	See also F3064

ASTM F3239 Standard Specification for Aircraft Electric Propulsion Systems	**Notes**
6.2 Controls	
6.3 Powerplant Operational Characteristics and Installation	See also F3064
6.3.1 General 6.3.2 Cooling Test Requirements 6.3.3 Starting and Stopping 6.3.3.4 Restart Envelope 6.3.3.5 Restart Capability 6.3.4 Powerplant Limitations 7. Hazard Mitigation	 See also F3064. Cooling tests must account for hot day conditions as relates to component thermal limits. Refer to AC 23.16 See also F3064. Reminder - Aeroplane Flight Manual required Must meet F3066
7.2 High Energy Rotors	See also F3061
7.3 Fire Protection 7.3.1.1 The EPU or ESS section is a designated fire zone. If a fire hazard exists.	***Identifies EPU or ESS as a designated fire zone***
7.3.2 Fire Protection 7.3.3 Lightning Protection 7.4 Ice Protection	 See also F3120

2.5.5 ASTM F3264, Specification for Normal Category Aeroplanes Certification, §8. Powerplant

8. Powerplant	**Notes**
8.1 Powerplant Installation:	
8.1.1 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.1.2 F3063/F3063M – 18a Standard Specification for Aircraft Fuel and Energy Storage and Delivery	
8.1.3 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	
8.1.4 F3065/F3065M – 18 Standard Specification for Aircraft Propeller System Installation	
8.1.5 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
8.2 Power or Thrust Control Systems:	
8.2.1 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.2.2 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	
8.3 Powerplant Installation Hazard Assessment:	
8.3.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
8.3.2 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.3.3 F3063/F3063M – 18a Standard Specification for Aircraft Fuel and Energy Storage and Delivery	
8.3.4 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	
8.3.5 F3065/F3065M – 18 Standard Specification for Aircraft Propeller System Installation	
8.3.6 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
8.3.7 F3117 – 18b Standard Specification for Crew Interface in Aircraft	
8.4 Powerplant Installation Ice Protection:	
8.4.1 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.4.2 F3063/F3063M – 18a Standard Specification for Aircraft Fuel and Energy Storage and Delivery	
8.4.3 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
8.5 Reversing Systems:	
8.5.1 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	

8. Powerplant	Notes
8.5.2 F3065/F3065M – 18 Standard Specification for Aircraft Propeller System Installation	
8.6 Powerplant Operational Characteristics:	
8.6.1 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.6.2 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	
8.6.3 F3065/F3065M – 18 Standard Specification for Aircraft Propeller System Installation	
8.6.4 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
8.6.5 F3117 – 18b Standard Specification for Crew Interface in Aircraft	
8.7 Fuel and Energy Storage and Distribution Systems:	
8.7.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
8.7.2 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.7.3 F3063/F3063M – 18a Standard Specification for Aircraft Fuel and Energy Storage and Delivery	
8.7.4 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	
8.7.5 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
8.7.6 F3114 – 15 Standard Specification for Structures	
8.8 Powerplant Induction, Exhaust, and Support Systems:	
8.8.1 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.8.2 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
8.9 Powerplant Installation Fire Protection:	
8.9.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
8.9.2 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
8.9.3 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	
8.9.4 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
8.10 Powerplant Installation Information	

2.6 Subpart F, Equipment

2.6.1 Unique Aspects of X-57 to This Subpart

The approach to Subpart F is to show where X-57 are applicable or have unique differences.

2.6.2 Certification Basis

Subpart F—Equipment	Notes
§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—	Applicable to X-57.
(1) Meet the level of safety applicable to the certification and performance level of the airplane; and	Applicable to X-57.
(2) Perform their intended function throughout the operating and environmental limits for which the airplane is certificated.	Applicable to X-57.
(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.	Applicable to X-57.
§23.2505 Function and installation.	
When installed, each item of equipment must function as intended.	
§23.2510 Equipment, systems, and installations.	To be described for X-57

Subpart F—Equipment	Notes
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:	Applicable to X-57 and all aircraft types. An approach that integrates the system safety analysis with the development of a certification basis and means of compliance is necessary for all novel aircraft types including the X-57.
(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.	Not applicable to X-57
An airplane approved for IFR operations must meet the following requirements, unless an applicant shows that exposure to lightning is unlikely:	
(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—	While originally written for aircraft equipment (think power for avionics for CNS, lighting, environmental, etc.) this is also the main reference attempting to be applied to ESS supporting EPUs. Associated MoC is through AC 20-184 and DO-311A.
(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	
(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.	

Subpart F—Equipment	Notes
§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.	Not applicable to X-57
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.	Not applicable to X-57
Pressurized systems must withstand appropriate proof and burst pressures.	
§23.2550 Equipment containing high-energy rotors.	Consideration for High-Lift Motor-Propellers
Equipment containing high-energy rotors must be designed or installed to protect the occupants and airplane from uncontained fragments.	

2.6.3 ASTM F3264, Specification for Normal Category Aeroplanes Certification, §9. Equipment

9. Equipment	Notes
9.1 Systems and Equipment Function and Safety Requirements:	
9.1.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.1.1.1 F3230 – 17 Standard Practice for Safety Assessments of Systems and Equipment in Small Aircraft	
9.1.1.2 F3231/F3231M – 17 Standard Specification for Electrical Systems in Small Aircraft	
(a) F3235 – 17a Standard Specification for Aircraft Storage Batteries	
9.1.1.3 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
9.1.1.4 F3233/F3233M – 17 Standard Specification for Instrumentation in Small Aircraft	
(a) F3229/F3229M – 17 Standard Practice for Static Pressure System Tests in Small Aircraft	
9.1.1.5 F3309/F3309M – 18 Standard Practice for Simplified Safety Assessment of Systems and Equipment in Small Aircraft	
9.1.2 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	
9.1.3 F3066/F3066M – 18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	
9.1.4 F3117 – 18b Standard Specification for Crew Interface in Aircraft	
9.1.5 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation Aircraft	
9.2 Equipment Function and Installation Requirements:	
9.2.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.2.1.1 F3231/F3231M – 17 Standard Specification for Electrical Systems in Small Aircraft	
(a) F3235 – 17a Standard Specification for Aircraft Storage Batteries	
9.2.1.2 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
9.2.1.3 F3233/F3233M – 17 Standard Specification for Instrumentation in Small Aircraft	
9.2.2 F3117 – 18b Standard Specification for Crew Interface in Aircraft	
9.3 Equipment, Systems, and Installation:	

9. Equipment	Notes
9.3.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.3.1.1 F3230 – 17 Standard Practice for Safety Assessments of Systems and Equipment in Small Aircraft	
9.3.1.2 F3235 – 17a Standard Specification for Aircraft Storage Batteries	
9.3.1.3 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	
9.3.1.4 F3233/F3233M – 17 Standard Specification for Instrumentation in Small Aircraft	
9.3.1.5 F3227/F3227M – 17 Standard Specification for Environmental Systems in Small Aircraft	
9.4 Electrical and Electronic System Lightning Protection:	
9.4.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.5 High Intensity Radiated Fields (HIRF) Protection:	
9.5.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.5.1.1 F3236 – 17 Standard Specification for High Intensity Radiated Field (HIRF) Protection in Small Aircraft	
9.6 System Power Generation, Storage, and Distribution:	
9.6.1 F2490 – 05 (2013) Standard Guide for Aircraft Electrical Load and Power Source Capacity Analysis	
9.6.2 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.6.2.1 F3231/F3231M – 17 Standard Specification for Electrical Systems in Small Aircraft	
9.6.2.2 F3233/F3233M – 17 Standard Specification for Instrumentation in Small Aircraft	
9.6.3 F3117 – 18b Standard Specification for Crew Interface in Aircraft	
9.6.4 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation Aircraft	
9.7 External and Cockpit Lighting:	
9.7.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.7.1.1 F3233/F3233M – 17 Standard Specification for Instrumentation in Small Aircraft	
9.7.1.2 F3234/F3234M – 17 Standard Specification for Exterior Lighting in Small Aircraft	
9.7.2 F3117 – 18b Standard Specification for Crew Interface in Aircraft	
9.7.3 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation Aircraft	
9.8 Safety Equipment:	
9.8.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.9 Flight in Icing Conditions:	
9.9.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.9.1.1 F3233/F3233M – 17 Standard Specification for Instrumentation in Small Aircraft	
9.9.2 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation Aircraft	
9.10 Pressurized System Elements:	
9.10.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.10.2 F3229/F3229M – 17 Standard Practice for Static Pressure System Tests in Small Aircraft	
9.11 Equipment Containing High-Energy Rotors:	
9.11.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.12 Installation of Cockpit Recorders:	
9.12.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.12.1.1 F3228 – 17 Standard Specification for Flight Data and Voice Recording in Small Aircraft	
9.13 Installation of Flight Data Recorders:	
9.13.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	
9.13.1.1 F3228 – 17 Standard Specification for Flight Data and Voice Recording in Small Aircraft	

2.7 Subpart G, Flightcrew Interface and Other Information

2.7.1 Unique Aspects of X-57 to This Subpart

The approach to Subpart G is to relate flightcrew interface certification requirements to the X-57 design and identify gaps in regulations and-or design considerations. The prime focus here will be the aircrew interface with the cruise and high-lift propulsive systems. The primary focus is the thrust levers, high-lift motor deployment device(s), propulsion displays/indicators, and associated automated flight control augmentation systems. The X-57 design presents unique challenges when considering inoperative propulsion components, associated displays, annunciations of failures, and aircrew corrective actions required for continued safe flight and landing as required. The normal operating concept of the cruise and high-lift propulsion systems must be well-defined and understood before considering abnormal and non-normal operating procedures.

2.7.2 Certification Basis

Subpart G—Flightcrew Interface and Other Information	**Notes**
§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.	Applies to X-57. Propulsion display of critical operating propulsion parameters required. Propulsive motor control must be intuitive and provide positive feedback of cruise and high-lift motor state.
(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.	Applies to X-57. Note: the notional engine display covered in briefing slides is likely unacceptable due to information overload, lack of trend data, and possibly warning, caution and annunciation capability.
(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.	Not applicable
§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.	Applies to X-57. Retaining conventional power levers is satisfactory. HLP mode switch selectable is likely satisfactory. Location for HLP mode switch and annunciators should be logically grouped.
(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.	Applies to X-57. State data of propulsive and associated electronic control systems is required. Intuitive annunciation of caution, warning, and alerts required.
(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.	Applies to X-57. See above. Applies to propulsive motors and associated electronic controllers for both propulsive systems.
§23.2610 Instrument markings, control markings, and placards.	Applies to X-57
(a) Each airplane must display in a conspicuous manner any placard and instrument marking necessary for operation.	Applies to X-57
(b) The design must clearly indicate the function of each cockpit control, other than primary flight controls.	Applies to X-57. See above comments for propulsive systems.
(c) The applicant must include instrument marking and placard information in the Airplane Flight Manual.	Applies to X-57
§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—	Applies to X-57. Powerplant display of information must show normal/non-normal operating states of all propulsive systems along with displays for controlling them.
(1) Be presented in a manner that the crewmember can monitor the parameter and determine trends, as needed, to operate the airplane; and	Applies to X-57
(2) Include limitations, unless the limitation cannot be exceeded in all intended operations.	Applies to X-57
(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—	

Subpart G—Flightcrew Interface and Other Information	Notes
(1) Not inhibit the primary display of flight or powerplant parameters needed by any flightcrew member in any normal mode of operation; and	Applies to X-57
(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.	Applies to X-57. Propulsive system failures, singly and in combination must permit enough control parameter information and associated annunciations to permit safe flight and landing.
§23.2620 Airplane flight manual.	
The applicant must provide an Airplane Flight Manual that must be delivered with each airplane.	Applies to X-57. Standard information requirements that are similar to Part 23 earlier amendments.
(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.	Extensive description of distributed propulsion systems components, information display, normal operation, abnormal, emergency operation required.
(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	Applies to X-57
(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.	Not applicable

2.7.3 ASTM F3264, Specification for Normal Category Aeroplanes Certification, §10. Flight Crew Interface and Other Information

10. Flight Crew Interface and Other Information	Notes
10.1 Flightcrew Compartment Interface:	Described above from a crew interface perspective. Systems and equipment DERs expertise required here as well.
10.1.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	Applies to X-57. This is a top level spec that refers to other specs for more specific systems requirements
10.1.1.1 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	Addresses largely mechanical control, autopilot, stab augmentation requirements, and stall barrier system requirements. Potential gap if HLP are considered flaps/slats and treated as such for certification purposes.
10.1.2 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
10.1.3 F3063/F3063M – 18a Standard Specification for Aircraft Fuel and Energy Storage and Delivery	
10.1.4 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	Applies to X-57. Powerplant instrumentation requirements described here. There is a gap in the ASTM standards for this requirement with regard to distributed electric propulsion systems. Display of distributed propulsive information and associated electrical status /control system information requires development by OEM and agreement of FAA.
10.1.5 F3117 – 18b Standard Specification for Crew Interface in Aircraft	Same comments from above apply to this standard.
10.2 Installation and Operation Information:	
10.2.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	Applies to X-57. This is a top level spec that refers to other specs for more specific systems requirements
10.2.1.1 F3227/F3227M – 17 Standard Specification for Environmental Systems in Small Aircraft	
10.2.1.2 F3231/F3231M – 17 Standard Specification for Electrical Systems in Small Aircraft	

10. Flight Crew Interface and Other Information	**Notes**
10.2.1.3 F3232/F3232M – 17 Standard Specification for Flight Controls in Small Aircraft	Applies to X-57. Cockpit controls, displays, arrangement, visibility, usability, marking, placard requirements described here. Particularly relevant to propulsion displays and control of cruise/high-lift motors.
10.2.1.4 F3233/F3233M – 17 Standard Specification for Instrumentation in Small Aircraft	Applies to X-57
10.2.2 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
10.2.3 F3063/F3063M – 18a Standard Specification for Aircraft Fuel and Energy Storage and Delivery	
10.2.4 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	Applies to X-57. Powerplant instrumentation requirements described here. See comment above.
10.2.5 F3117 – 18b Standard Specification for Crew Interface in Aircraft	Same comments from above apply to this standard.
10.2.6 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation	NA
10.3 Instrument Markings, Control Markings, and Placards:	
10.3.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	Applies to X-57. This is a top level spec that refers to other specs for more specific systems requirements.
10.3.2 F3063/F3063M – 18a Standard Specification for Aircraft Fuel and Energy Storage and Delivery	
10.3.3 F3117 – 18b Standard Specification for Crew Interface in Aircraft	Applies to X-57
10.3.4 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation Aircraft	NA
10.4 Flight, Navigation, and Powerplant Instruments:	
10.4.1 F3061/F3061M – 17 Standard Specification for Systems and Equipment in Small Aircraft	Applies to X-57. Same comment as above.
10.4.2 F3062/F3062M – 18 Standard Specification for Aircraft Powerplant Installation	
10.4.3 F3064/F3064M – 18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	Applies to X-57. Powerplant instrumentation requirements described here. See comments above
10.5 Airplane Flight Manual:	
10.5.1 F3117 – 18b Standard Specification for Crew Interface in Aircraft	Applies to X-57
10.5.2 F3174/F3174M – 18 Standard Specification for Establishing Operating Limitations and Information for Aeroplanes	Very similar to Part 23-63 requirements for identifying operational limits and associated information. Refer to earlier comments on speed and aircraft configuration development.
10.5.3 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation Aircraft	NA
10.6 Instructions for Continued Airworthiness:	
10.6.1 F3120/F3120M – 15 Standard Specification for Ice Protection for General Aviation	NA
10.6.2 F3117 – 18b Standard Specification for Crew Interface in Aircraft	NA

2.8 Appendix A, Instructions for Continued Airworthiness

2.8.1 Unique Aspects of X-57 to This Subpart

The approach to the Instructions for Continued Airworthiness (ICA) will be developed after the "Draft X-57 Reference to Compliance Checklist" is developed. The following "Certification Basis" is shown for completeness.

2.8.2 Certification Basis

Appendix A to Part 23—Instructions for Continued Airworthiness	**Notes**
A23.1 General	
(a) This appendix specifies requirements for the preparation of Instructions for Continued Airworthiness as required by this part.	
(b) The Instructions for Continued Airworthiness for each airplane must include the Instructions for Continued Airworthiness for each engine and propeller (hereinafter designated “products”), for each appliance required by this chapter, and any required information relating to the interface of those appliances and products with the airplane. If Instructions for Continued Airworthiness are not supplied by the manufacturer of an appliance or product installed in the airplane, the Instructions for Continued Airworthiness for the airplane must include the information essential to the continued airworthiness of the airplane.	
(c) The applicant must submit to the FAA a program to show how changes to the Instructions for Continued Airworthiness made by the applicant or by the manufacturers of products and appliances installed in the airplane will be distributed.	
A23.2 Format	
(a) The Instructions for Continued Airworthiness must be in the form of a manual or manuals as appropriate for the quantity of data to be provided.	
(b) The format of the manual or manuals must provide for a practical arrangement.	
A23.3 Content	
The contents of the manual or manuals must be prepared in the English language. The Instructions for Continued Airworthiness must contain the following manuals or sections and information:	
(a) Airplane maintenance manual or section.	
(1) Introduction information that includes an explanation of the airplane's features and data to the extent necessary for maintenance or preventive maintenance.	
(2) A description of the airplane and its systems and installations including its engines, propellers, and appliances.	
(3) Basic control and operation information describing how the airplane components and systems are controlled and how they operate, including any special procedures and limitations that apply.	
(4) Servicing information that covers details regarding servicing points, capacities of tanks, reservoirs, types of fluids to be used, pressures applicable to the various systems, location of access panels for inspection and servicing, locations of lubrication points, lubricants to be used, equipment required for servicing, tow instructions and limitations, mooring, jacking, and leveling information.	
(b) Maintenance Instructions.	
(1) Scheduling information for each part of the airplane and its engines, auxiliary power units, propellers, accessories, instruments, and equipment that provides the recommended periods at which they should be cleaned, inspected, adjusted, tested, and lubricated, and the degree of inspection, the applicable wear tolerances, and work recommended at these periods. However, the applicant may refer to an accessory, instrument, or equipment manufacturer as the source of this information if the applicant shows that the item has an exceptionally high degree of complexity requiring specialized maintenance techniques, test equipment, or expertise. The recommended overhaul periods and necessary cross reference to the Airworthiness Limitations section of the manual must also be included. In addition, the applicant must include an inspection program that includes the frequency and extent of the inspections necessary to provide for the continued airworthiness of the airplane.	
(2) Troubleshooting information describing probable malfunctions, how to recognize those malfunctions, and the remedial action for those malfunctions.	
(3) Information describing the order and method of removing and replacing products and parts with any necessary precautions to be taken.	
(4) Other general procedural instructions including procedures for system testing during ground running, symmetry checks, weighing and determining the center of gravity, lifting and shoring, and storage limitations.	
(c) Diagrams of structural access plates and information needed to gain access for inspections when access plates are not provided.	
(d) Details for the application of special inspection techniques including radiographic and ultrasonic testing where such processes are specified by the applicant.	
(e) Information needed to apply protective treatments to the structure after inspection.	

Appendix A to Part 23—Instructions for Continued Airworthiness	**Notes**
(f) All data relative to structural fasteners such as identification, discard recommendations, and torque values.	
(g) A list of special tools needed.	
(h) In addition, for level 4 airplanes, the following information must be furnished—	
(1) Electrical loads applicable to the various systems;	
(2) Methods of balancing control surfaces;	
(3) Identification of primary and secondary structures; and	
(4) Special repair methods applicable to the airplane.	
A23.4 Airworthiness limitations section.	
The Instructions for Continued Airworthiness must contain a section titled Airworthiness Limitations that is segregated and clearly distinguishable from the rest of the document. This section must set forth each mandatory replacement time, structural inspection interval, and related structural inspection procedure required for type certification. If the Instructions for Continued Airworthiness consist of multiple documents, the section required by this paragraph must be included in the principal manual. This section must contain a legible statement in a prominent location that reads "The Airworthiness Limitations section is FAA approved and specifies maintenance required under §§43.16 and 91.403 of Title 14 of the Code of Federal Regulations unless an alternative program has been FAA approved."	

3 Aircraft Engines

Under the provisions of 14 CFR 21.17(a)(1), an aircraft engine manufacturer must meet the applicable provisions of 14 CFR Part 33 in effect on the date of application for a type certificate.

If the Administrator finds that the applicable airworthiness regulations (e.g., 14 CFR part 33) do not contain adequate or appropriate safety standards for new engine types because of a novel or unusual design feature, special conditions may be prescribed under the provisions of §21.16.

Special conditions are initially applicable to the model for which they are issued. Should the type certificate for that model be amended later to include any other engine model that incorporates the same novel or unusual design feature, these special conditions would apply to the other engine model under § 21.101.

The FAA issues special conditions, as defined in 14 CFR 11.19, under §11.38, and they become part of the type certification basis under §21.17(a)(2).

On 19 November 2020, the FAA issued the first set of special conditions for a 375 and 750 SHP electric propulsion unit (EPU) which are in the process of certification by magniX[8]. Given that both electric motors are designed to accept propellers and rely on 2×3-phase inverter architecture for redundancy, this special condition applies to the X-57 in most respects.

The new and novel features of the magniX EPUs which led to the decision to produce this set of special conditions is best explained in the following excerpts from the text published in the Federal Register. It should be noted that this special condition text represents a proposed special condition and was released on 19 November 2020 for public comment[9]. The following text should not be relied on in the future without consulting the Federal Register for the final release.

The following text should not be relied on in the future without consulting the Federal Register for the final release.

A preamble section of the magniX special condition makes the following determination concerning 14 CFR 33's alignment with gas turbine and reciprocating engines:

Aircraft engines make use of an energy source to drive mechanical systems that provide propulsion for the aircraft. Energy can be generated from various sources such as petroleum and natural gas. The turbine and reciprocating aircraft engines certified under part 33 use aviation fuel for an energy source. The reciprocating and turbine engine technology that was anticipated in the development of part 33 converts air and fuel to energy using an internal combustion system, which generates heat and mass flow of combustion products for turning shafts that are attached to propulsion devices such as propellers and ducted fans. Part 33 regulations set forth standards for these engines and mitigate potential hazards resulting from failures and malfunctions. The nature, progression, and severity of engine failures are tied closely to the technology that is used to design and manufacture aircraft engines. These technologies involve chemical, thermal, and mechanical systems. Therefore, the existing engine regulations in part 33 address certain chemical, thermal, and mechanically induced

[8] Federal Register, Docket ID FAA-2020-0894, *magniX USA, Inc., magni250 and magni500 Model Engines,* Notice of Proposed Special Conditions, Published November 19, 2020 with comments closing on December 21, 2020. See https://www.federalregister.gov/documents/2020/11/19/2020-23434/special-conditions-magnix-usa-inc-magni250-and-magni500-model-engines
[9] Ibid.

failures that are specific to air and fuel combustion systems operating with cyclically loaded high-speed, high-temperature, and highly-stressed components.

The existing part 33 airworthiness standards for aircraft engines date back to 1965. These airworthiness standards are based on fuel-burning reciprocating and turbine engine technology. The magni250 and magni500 model engines are not turbine or reciprocating engines. These engines have a novel or unusual design feature, which is the use of electrical sources of energy instead of fuel to drive the mechanical systems that provide propulsion for aircraft. The aircraft engine is also exposed to chemical, thermal, and mechanical operating conditions, unlike those observed in internal combustion systems. Therefore, part 33 does not contain adequate or appropriate safety standards for the magni250 and magni500 model engine's novel design feature.

magniX's proposed aircraft engines will operate using electrical power instead of air and fuel combustion to propel the aircraft. These electric engines will be designed, manufactured, and controlled differently than turbine or reciprocating aircraft engines. They will be built with an electric motor, controller, and high-voltage systems that draw energy from electrical storage or generating systems. The electric motor is a device that converts electrical energy into mechanical energy by electric current flowing through wire coils in the motor producing a magnetic field that interacts with the magnets on the rotating shaft. The controller is a system that consists of two main functional elements: the motor controller and an electric power inverter to drive the motor. The high voltage system is a combination of wires and the connectors that couple the motor and the controller.

In addition, the technology required to produce these high-voltage and high-current electronic components introduces potential hazards that do not exist in turbine and reciprocating aircraft engines. For example, high-voltage transmission lines, electromagnetic shields, magnetic materials, and high-speed electrical switches are necessary to use the physical properties essential to the electric engine. However, this technology also exposes the aircraft to potential failures that are not common to gas-powered turbine and reciprocating engines, which could adversely affect safety.

Although the electric aircraft engines proposed by magniX use novel or unusual design features that are not addressed in the existing part 33 airworthiness standards, there are some basic similarities in configuration and function that require similar provisions to prevent hazards that are common to aircraft engines using air and fuel combustion (e.g., fire, uncontained high-energy debris, and loss of thrust control). However, the primary failure concerns and the probability of exposure to common hazards are different for the proposed electric aircraft engines. This creates a need to develop special conditions to ensure the engine's safety and reliability.

The requirements in part 33 ensure the design and construction of aircraft engines, including the engine control systems, are proper for the engine type design and operating limits. However, part 33 does not fully address the use of aircraft engines like magniX's, which operate using electrical technology as the primary means of propelling the aircraft. This necessitates the development of special conditions to provide adequate airworthiness standards for these aircraft engines.

The requirements in part 33, subpart B, are applicable to reciprocating and turbine aircraft engines. Subparts C and D are applicable to reciprocating aircraft engines. Subparts E *through G are applicable to turbine aircraft engines. As such, subparts B through G do not adequately address the use of aircraft engines that operate using electrical technology. This necessitates the development of special conditions to ensure a level of safety commensurate with these subparts, as those regulatory requirements do not contain adequate or appropriate safety standards for aircraft engines that operate using electrical technology to propel the aircraft.*

3.1 Overview of the Special Conditions That the FAA Proposes

The special conditions that the FAA proposes for magniX's engine design include:

1. ***Applicability:*** Proposed special condition No. 1 would require magniX to comply with 14 CFR part 33, except for those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines.
2. ***Engine Ratings and Operating Limitations:*** Proposed special condition No. 2 would require magniX, in addition to compliance with 14 CFR 33.7(a), to establish engine operating limits related to the power, torque, speed, and duty cycles specific to the magni250 and magni500 model engines. The duty or duty cycle is a statement of the load(s) to which the engine is subjected, including, if applicable, starting, no-load, and rest, and de-energized periods, including their durations or cycles and sequence in time.
3. ***Materials*:** Proposed special condition No. 3 would require magniX to comply with 14 CFR 33.15, which sets requirements for the suitability and durability of materials used in the engine, which would otherwise apply only to reciprocating and turbine aircraft engines.
4. ***Fire Protection*:** Proposed special condition No. 4 would require magniX to comply with 14 CFR 33.17, which sets requirements to protect the engine and specific parts and components of the airplane against fire, which would otherwise apply only to reciprocating and turbine aircraft engines. Additionally, this proposed special condition would require magniX to ensure that the high-voltage electrical wiring interconnect systems that connect the controller to the motor are protected against arc-faults. An arc-fault is a high-power discharge of electricity between two or more conductors, and this discharge generates heat, which can break down the wire's insulation and trigger an electrical fire. Arc-faults can range in power from a few amps up to thousands of amps and are highly variable in strength and duration.
5. ***Durability*:** Proposed special condition No. 5 would require the proposed engine design and construction to ensure safe engine operation between maintenance intervals, overhaul periods, and mandatory actions. This proposed condition would require magniX to develop maintenance instructions and scheduling information.
6. ***Engine Cooling*:** Proposed special condition No. 6 would require magniX to comply with 14 CFR 33.21, which requires the engine design and construction to provide necessary cooling, which would otherwise apply only to reciprocating and turbine aircraft engines. Additionally, this proposed special condition would require magniX to document the cooling system monitoring features and usage in the engine installation manual, following §33.5, if cooling is required to satisfy the safety analysis described in proposed special condition no. 17. Loss of adequate cooling to an engine that operates using electrical technology can result in rapid overheating and abrupt engine failure with critical consequences to safety.

7. ***Engine Mounting Attachments and Structure:*** Proposed special condition No. 7 would require magniX and the proposed design to comply with 14 CFR 33.23, which requires the applicant to define, and the proposed design to withstand certain load limits for the engine mounting attachments and related engine structure. These requirements would otherwise apply only to reciprocating and turbine aircraft engines.
8. ***Accessory Attachments*:** Proposed special condition No. 8 would require the proposed design to comply with 14 CFR 33.25, which sets certain design, operational, and maintenance requirements for the engine's accessory drive and mounting attachments and would otherwise apply only to reciprocating and turbine aircraft engines.
9. ***Overspeed:*** Proposed special condition No. 9 would require magniX to establish by test, validated analysis, or a combination of both, that – (1) the rotor overspeed must not result in a burst, rotor growth, or damage that results in a hazardous engine effect; (2) rotors must possess sufficient strength margin to prevent burst; and (3) operating limits must not be exceeded in-service. The proposed special condition associated with rotor overspeed is necessary because of the differences between turbine engine technology and the technology of these electric engines. Turbine speed is driven by hot air expansion and is impacted by the aerodynamic loads on the rotor blades. Therefore, the speed or overspeed is not directly controlled in turbine engines. The speed of an electric engine is directly controlled by the electric field created by the controller. The failure modes that can lead to overspeed between turbine engines and these engines are vastly different, and therefore this special condition is necessary.
10. ***Engine Control Systems:*** Proposed special condition No. 10(b) would require magniX to ensure that these engines do not experience any unacceptable operating characteristics (such as unstable speed or torque control) or exceed any of their operating limitations.
    a) The FAA originally issued §33.28 at amendment 33-15 to address the evolution of the means of controlling the fuel supplied to the engine, from carburetors and hydro-mechanical controls to electronic control systems. These electronic control systems grew in complexity over the years, and as a result, the FAA amended §33.28 at amendment 33-26 to address these increasing complexities. The controller that forms the controlling system for these electric engines is significantly simpler than the complex control systems used in modern turbine engines. The current regulations for engine control are inappropriate for electric engine control systems; therefore, the proposed special condition no. 10(b) associated with controlling these engines is necessary.
    b) Proposed special condition No. 10(c) would require magniX to develop and verify the software and complex electronic hardware used in programmable logic devices, using proven methods that ensure it can provide the accuracy, precision, functionality, and reliability commensurate with the hazard that is being mitigated by the logic. RTCA DO-254, *Design Assurance Guidance for Airborne Electronic Hardware,* dated April 19, 2000,[10] *distinguishes* between complex and simple electronic hardware.
    c) Proposed special condition no. 10(d) would require data from assessments of all functional aspects of the control system to prevent errors that could exist in software programs that are not readily observable by inspection of the code. Also, magniX must use methods that will result in the expected quality that ensures the engine control system performs the intended functions throughout the declared operational

[10] https://my.rtca.org/NC__Product?id=a1B36000001IcjTEAS

envelope.

d) The environmental limits referred to in proposed special condition no. 10(e) include temperature, vibration, HIRF, and others addressed in RTCA DO-160G, *Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments*.[11] Accordingly, proposed special condition no. 10(e) would require magniX to document the environmental limits to which the system has been qualified in the engine installation instructions.
e) Proposed special condition no. 10(f) would require magniX to evaluate various control system failures to assure that these failures will not lead to unsafe conditions. The FAA issued Advisory Circular, AC 33.28-3, *Guidance Material For 14 CFR § 33.28, Engine Control Systems,* on May 23, 2014.[12] Paragraph 6-2 of this AC provides guidance on defining an engine control system failure when showing compliance with the requirements of 14 CFR 33.28. AC 33.28-3 also includes objectives for the integrity requirements, criteria for a loss of thrust (or power) control (LOTC/LOPC) event, and an acceptable LOTC/LOPC rate. As with other topics within these proposed special conditions, the failure rates that apply to electric engines were not established when the FAA issued this AC.
f) The phrase "in the full-up configuration" is used in proposed special condition no. 10(f)(2) refers to a system without any fault conditions present. The electronic control system must when in the full-up configuration, be single fault-tolerant, as determined by the Administrator, for electrical, electrically detectable, and electronic failures involving LOPC events.
g) The term "local" in the context of "local events" used in the proposed special condition no. 10(f)(4) means failures or malfunctions leading to events in the intended aircraft installation such as fire, overheat, or failures leading to damage to engine control system components. These local events must not result in a hazardous engine effect due to engine control system failures or malfunctions.
h) Proposed special condition no. 10(g) would require magniX to conduct a safety assessment of the control system to support the safety analysis in special condition no. 17. This control safety assessment provides failures and rates of these failures that can be used at the aircraft safety assessment level.
i) Proposed special condition no. 10(h) requires magniX to provide appropriate protection devices or systems to ensure that engine operating limitations will not be exceeded in-service.
j) Proposed special condition no. 10(i) is necessary to ensure the controllers are self-sufficient and isolated from other aircraft systems. The aircraft-supplied data supports the analysis at the aircraft level to protect the aircraft from common mode failures that could lead to major propulsion power loss. The exception "other than power command signals from the aircraft" noted in proposed special condition no. 10(i) is based on the FAA's determination that there are no reasonable means for the engine controller to determine the validity of any in-range signals from this system. In many cases, the engine control system can detect a faulty signal from the aircraft. The engine control system typically accepts the power command signal as a valid value.

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[11] https://my.rtca.org/NC__Product?id=a1B36000001IcnSEAS
[12] https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_33_28-3.pdf

k) The term “independent” in the context of “fully independent engine systems” is referenced in proposed special condition no. 10(i) means the controllers should be self-sufficient and isolated from other aircraft systems or provide redundancy that enables them to accommodate aircraft data system failures. In the case of loss, interruption, or corruption of aircraft-supplied data, the engine must continue to function in a safe and acceptable manner without unacceptable effects on thrust or power, hazardous engine effects, or inability to comply with the operation demonstrations in the proposed special condition no. 25.

l) The term “accommodated” in the context of “detected and accommodated” is referenced in proposed special condition no. 10(i)(2) is to assure that once a fault has been detected that the system continues to function safely.

m) Proposed special condition no. 10(j) would require magniX to show that the loss of electric power from the aircraft will not cause the electric engine to malfunction in a manner hazardous to the aircraft. The total loss of electric power to the electric engine may result in an engine shutdown.

11. ***Instrument Connection*:** Proposed special condition No. 11 would require magniX to comply with 14 CFR 33.29(a), (e), (f), and (g), which set certain requirements for the connection and installation of instruments to monitor engine performance. The remaining requirements in section 33.29 apply only to technologies used in reciprocating and turbine aircraft engines.

    Instrument connections (wires, wire insulation, potting, grounding, connector designs) present opportunities for unsafe features to be present on the aircraft. Proposed special condition no. 11 would require the safety analysis to include potential hazardous effects from failure of instrument connections to function properly. The outcome of this analysis might identify the need for design enhancements or additional Instructions for Continued Airworthiness (ICA) to ensure safety.

12. ***Stress Analysis:*** Section 33.62 requires applicants to perform a stress analysis on each turbine engine. This regulation is explicitly applicable only to turbine engines and turbine engine components, and not appropriate for the magniX magni250 and magni500 model engines. However, the FAA proposes that a stress analysis particular to these electric engines is necessary.

    Proposed special condition No. 12 would require a mechanical, thermal, and electrical stress analysis to show there is a sufficient design margin to prevent unacceptable operating characteristics. Also, the applicant must determine the maximum stresses in the engine by tests, validated analysis, or a combination thereof, and show that they do not exceed minimum material properties.

13. ***Critical and Life-Limited Parts:*** Proposed special condition No. 13 would require magniX to show whether rotating or moving components, bearings, shafts, static parts, and non-redundant mount components should be classified, designed, manufactured, and managed throughout their service life as critical or life-limited parts.

    The engineering plan referenced in proposed special condition no. 13(b)(1) would require magniX to establish activities for managing documents, practices, and procedures that govern key design criteria essential to part airworthiness. The engineering plan would be required to contain methods for verifying the characteristics and qualities assumed in the design data using methods that are suitable for the part criticality. The engineering plan flows information from engineering to manufacturing about the criticality of key attributes that affect the airworthiness of the part. The plan also includes a reporting system that flows problematic issues that develop in engines while they operate in service so the design process can address them. For example, the effect of environmental influences on engine performance might not be consistent with the assumptions used to design the part. The impact of ice slab ingestion on engine parts might not be fully understood until the engine ingests the specific ice quantities and shapes that the airplane sheds. During the pre-certification activities, magniX must ensure the engineering plan is complete, available, and acceptable to the Administrator before the engine is certified. The term “low-cycle fatigue” referenced in proposed special condition no. 13(a)(2) is a decline in material strength from exposure to cyclic stress at levels beyond the stress threshold the material can sustain indefinitely. This threshold is known as the material endurance limit. Low-cycle fatigue typically causes a part to sustain plastic or permanent deformation during the cyclic loading and can lead to cracks, crack growth, and fracture. Engine parts that operate at high temperatures and high-mechanical stresses simultaneously can experience low-cycle fatigue coupled with creep. Creep is the tendency of a metallic material to permanently move or deform when it is exposed to the extreme thermal conditions created by hot combustion gasses and substantial physical loads such as high rotational speeds and maximum thrust. Conversely, high-cycle fatigue is caused by elastic deformation, small strains caused by alternating stress, and a much higher number of load cycles compared to the number of cycles that cause low-cycle fatigue.

The term “manufacturing definition” referenced in proposed special condition no. 13(b)(2) is the collection of data required to translate documented engineering design criteria into physical parts and verify that the parts comply with the properties established by the design data. Since engines are not intentionally tested to failure during a certification program, there are inherent expectations for performance and durability guaranteed by the documents and processes used to execute production and quality systems required by § 21.137. These systems limit the potential manufacturing outcomes to parts that are consistently produced within design constraints.

The manufacturing plan and service management plan ensure essential information from the engineering plan, such as the design characteristics that ensure the integrity of critical and life-limited parts, is consistently produced and preserved over the lifetime of those parts. The manufacturing plan includes special processes and production controls to prevent inclusion of manufacturing-induced anomalies, which can degrade the part’s structural integrity. Examples of manufacturing-induced anomalies are material contamination, unacceptable grain growth, heat affected areas, and residual stresses. The service management plan has provisions for enhanced detection and reporting of service-induced anomalies that can cause the part to fail before it reaches its life limit or service limit. Anomalies can develop in service from improper handling, unforeseen operating conditions, and long-term environmental effects. The service management plan ensures important information that might affect the assumptions used to design a part is incorporated into the design process to remove unforeseen potential unsafe features from the engine.

14. ***Lubrication System:*** Proposed special condition No. 14 would require magniX to ensure the lubrication system is designed to function properly between scheduled maintenance intervals and prevent contamination of the engine bearings. This proposed condition would also require magniX to demonstrate the unique lubrication attributes and functional capability of the magni250 and magni500 model engine design.

    The corresponding part 33 regulations include provisions for lubrication systems used in reciprocating and turbine engines. The part 33 requirements account for safety issues associated with specific reciprocating and turbine engine system configurations. These regulations are not appropriate for the magniX magni250 and magni500 model engines. For example, these engines do not have a crankcase or lubrication oil sump. The bearings are sealed, so they do not require an oil circulation system. The lubrication system in these engines is also independent of the propeller pitch control system. Therefore, proposed special condition no. 14 incorporates only certain requirements from the part 33 regulations.
15. ***Power Response:*** Proposed special condition No. 15 would require the design and construction of the magni250 and magni500 model engines to enable an increase (1) from the minimum power setting to the highest-rated power without detrimental engine effects, and (2) from the minimum obtainable power while in-flight and on the ground to the highest-rated power within a time interval for safe operation of the aircraft.

    The engine control system governs the increase or decrease in power in combustion engines to prevent too much (or too little) fuel from being mixed with air before combustion. Due to the lag in rotor response time, improper fuel/air mixtures can result in engine surges, stalls, and exceedances above rated limits and durations. Failure of the engine to provide thrust, maintain rotor speeds below burst thresholds, and temperatures below limits have the potential for detrimental effects to the aircraft. Similar detrimental effects are possible in the magni250 and magni500 model engines, but the causes are different. Electric engines with reduced power response time can experience insufficient thrust to the aircraft, shaft over-torque, and over-stressed rotating components, propellers, and critical propeller parts. Therefore, this special condition is necessary.
16. ***Continued Rotation*:** Proposed special condition No. 16 would require magniX to design the magni250 and magni500 model engines such that, if the main rotating systems continue to rotate after the engine is shut down while in-flight, this continued rotation will not result in any hazardous engine effects.

    The main rotating system of the magniX magni250 and magni500 model engines consists of the rotors, shafts, magnets, bearings, and wire windings that convert electrical energy to shaft torque. This rotating system must continue to rotate after the power source to the engine is shut down. The safety concerns associated with this proposed special condition are substantial asymmetric aerodynamic drag that can cause aircraft instability, loss of control, and reduced efficiency, and result in a forced landing or inability to continue safe flight.
17. ***Safety Analysis*:** Proposed special condition No. 17 would require magniX to comply with 14 CFR 33.75(a)(1), (a)(2), and (a)(3), which require the applicant to conduct a safety analysis of the engine, and which would otherwise be applicable only to turbine aircraft engines. Additionally, this proposed special condition would require magniX to assess its engine design to determine the likely consequences of failures that can

reasonably be expected to occur. The failure of such elements and associated prescribed integrity requirements must be stated in the safety analysis.

A primary failure mode is the manner in which a part is most likely going to fail. Engine parts that have a primary failure mode, a predictable life to the failure and a failure consequence that results in a hazardous effect are life-limited or critical parts. Some life-limited or critical engine parts can fail suddenly in their primary failure mode from prolonged exposure to normal engine environments such as temperature, vibration, and stress. Due to the consequence of failure, these parts are not allowed to be managed by on-condition or probabilistic means because the probability of failure cannot be sensibly estimated in numerical terms. Therefore, the parts are managed by compliance with integrity requirements such as mandatory maintenance (life limits, inspections, inspection techniques) to ensure the qualities, features, and other attributes that prevent the part from failing in its primary failure mode are preserved throughout its service life. For example, if the number of engine cycles to failure are predictable and can be associated with specific design characteristics, such as material properties, then the applicant can manage the engine part with life limits.

18. ***Ingestion:*** Proposed special condition No. 18 would require magniX to ensure that these engines will not experience unacceptable power loss or hazardous engine effects from ingestion. The associated regulation for turbine engines, 14 CFR 33.76, is based on potential damage from birds being ingested into the turbine engine that has an inlet duct, which directs air into the engine for combustion, cooling, and thrust. In contrast, these electric engines do not use an inlet for those purposes.

    An "unacceptable" power loss, as used in proposed special condition no. 18(a), is one in which the power or thrust required for safe flight of the aircraft becomes unavailable to the pilot. The specific amount of power loss required for safe flight depends on the aircraft configuration, speed, altitude, attitude, atmospheric conditions, phase of flight, and other circumstances where the demand for thrust is critical to safe operation of the aircraft.
19. ***Liquid Systems*:** Proposed special condition No. 19 would require magniX to ensure that liquid systems used for lubrication or cooling of engine components are designed and constructed to function properly. Also, if a liquid system is not self-contained, the interfaces to that system would be required to be defined in the engine installation manual. Liquid systems for the lubrication or cooling of engine components can include heat exchangers, pumps, fluids, tubing, connectors, electronic devices, temperature sensors and pressure switches, fasteners and brackets, bypass valves, and metallic chip detectors. These systems allow the electric engine to perform at extreme speeds and temperatures for durations up to the maintenance intervals without exceeding temperature limits or predicted deterioration rates.
20. ***Vibration Demonstration:*** Proposed special condition No. 20 would require magniX to ensure (1) the engine is designed and constructed to function throughout its normal operating range of rotor speeds and engine output power without inducing excessive stress caused by engine vibration, and (2) the engine design undergoes a vibration survey.

    The vibration demonstration is a survey that characterizes the vibratory attributes of the engine and verifies the stresses from vibration do not impose excessive force or result in natural frequency responses on the aircraft structure. The vibration demonstration also ensures internal vibrations will not cause engine components to fail. Excessive vibration force occurs at magnitudes and forcing functions or frequencies, which may result in damage to the aircraft. Stress margins to failure add conservatism to the highest values predicted by analysis for additional protection from failure caused by influences beyond those quantified in the analysis. The result of the additional design margin is improved engine reliability that meets prescribed thresholds based on the failure classification. The amount of margin needed to achieve the prescribed reliability rates depends on an applicant's experience with a product. The FAA considers the reliability rates when deciding how much vibration is "excessive."

21. ***Overtorque:*** Proposed special condition No. 21 would require magniX to demonstrate that the engine is capable of continued operation without the need for maintenance if it experiences a certain amount of overtorque.

    The electric engine proposed by magniX converts electrical energy to shaft torque, which is used for propulsion. The electric motor, controller, and high-voltage systems control the engine torque. When the pilot commands power or thrust, the engine responds to the command and adjusts the shaft torque to meet the demand. During the transition from one power or thrust setting to another, there is a small delay, or latency, in the engine response time. While the engine dwells in this time interval, it can continue to apply torque until the command to reduce the torque is applied by the engine control. The amount of overtorque the FAA permits during operation depends on how well the applicant demonstrates the engine's capability to remain operational without the need for maintenance action. Therefore, this special condition is necessary.
22. ***Calibration Assurance:*** Proposed special condition No. 22 would require magniX to subject the engine to calibration tests, to establish its power characteristics and the conditions both before and after the endurance and durability demonstrations specified in proposed special condition nos. 23 and 26. The calibration test requirements specified in §33.85 only apply to the endurance test specified in §33.87, which is applicable only to turbine engines. The FAA proposes that the methods used for accomplishing those tests for turbine engines is not the best approach for electric engines. The calibration tests in §33.85 have provisions applicable to ratings that are not relevant to the magniX magni250 and magni500 model engines. Proposed special condition no. 22 would allow magniX to demonstrate the endurance and durability of the electric engine either together or independently, whichever is most appropriate for the engine qualities being assessed. Consequently, the proposed special condition applies the calibration requirement to both the endurance and durability tests.
23. ***Endurance Demonstration*:** Proposed special condition No. 23 would require magniX to perform an endurance demonstration test that is acceptable to the Administrator. The Administrator will evaluate the extent to which the test exposes the engine to failures that could occur when the engine is operated at up to its rated values, to determine if the test is sufficient to show the engine design will not exhibit unacceptable effects in-service, such as significant performance deterioration, operability restrictions, engine power loss or instability, when it is run for sustained periods at extreme operating conditions.
24. ***Temperature Limit:*** Proposed special condition No. 24 would require magniX to ensure the engine can endure operation at its temperature limits plus an acceptable margin. An "acceptable margin," as used in the proposed special condition, is the amount of temperature above that required to prevent the least-capable engine allowed by the type

design from failing due to temperature-related causes when operating at the most extreme thermal conditions.

25. ***Operation Demonstration:*** Proposed special condition No. 25 would require the engine to demonstrate safe operating characteristics throughout its declared flight envelope and operating range. Engine operating characteristics define the range of functional and performance values the magniX magni250 and magni500 model engines can achieve without incurring hazardous effects. They are requisite capabilities of the type design that qualify the engine for installation into aircraft and determine aircraft installation requirements. The primary engine operating characteristics are assessed by the tests and demonstrations that would be required by these special conditions. Some of these characteristics are shaft output torque, rotor speed, power consumption, and engine thrust response. The engine performance data magniX will use to certify the engine must account for installation loads and effects. These are aircraft-level effects that could affect the engine characteristics that are measured in a test cell. These effects could result from elevated inlet cowl temperatures, extreme aircraft maneuvers, flowstream distortion, and hard landings. An engine run in a test facility could demonstrate more capability for some operating characteristics than it will when operating on an aircraft and potentially decrease the engine ratings and operating limits. Therefore, the installed performance defines the engine performance capabilities.
26. ***Durability Demonstration:*** Proposed special condition No. 26 would require magniX to subject the engine to a durability demonstration. The durability demonstration must show that each part of the engine is designed and constructed to minimize the development of any unsafe condition of the system between overhaul periods or between engine replacement intervals if the overhaul is not defined. Durability is the ability of an engine, in a fully deteriorated state, to continue generating rated power or thrust, retain adequate operating margins, and retain sufficient efficiency that enables the aircraft to reach its destination. The amount of deterioration an engine can experience is restricted by operating limitations and managed by the ICA. Section 33.90 specifies how maintenance intervals are established; it does not include provisions for an engine replacement. Electric engines and turbine engines deteriorate differently; therefore, magniX will use different test effects to establish overhaul periods or engine replacement intervals if no maintenance is specified.
27. ***System and Component Tests:*** Proposed special condition No. 27 would require magniX to show that the systems and components of the engine would perform their intended functions in all declared engine environments and operating conditions.

    Sections 33.87 and 33.91, which are specifically applicable to turbine engines, have conditional criteria to decide if additional tests will be required after the engine tests. The criteria are not suitable for electric engines. Part 33 associates the need for additional testing with the outcome of the § 33.87 endurance test because it is designed to address safety concerns in combustion engines. For example, § 33.91(b) establishes a need for temperature limits and additional testing where the endurance test does not fully expose internal components to thermal conditions that verify the desired operating limits. A safety concern for electric engines is extreme temperatures. The FAA proposes that the § 33.87 endurance test might not be the best way to achieve the highest thermal conditions for all the electronic components of electric engines because heat is generated differently in electronic systems than it is in turbine engines. There are also additional safety considerations that need to be addressed in the test. Therefore, proposed special condition no. 27 would be a performance-based requirement that allows magniX to determine how to challenge the electric engine and to determine the appropriate limitations that correspond to the technology.

28. ***Rotor Locking Demonstration:*** Proposed special condition No. 28 would require the engine to demonstrate reliable rotor locking performance and that no hazardous effects will occur if the engine uses a rotor locking device to prevent shaft rotation.

    Some engine designs enable the pilot to prevent a propeller shaft or main rotor shaft from turning while the engine is running, or the aircraft is in-flight. This capability is needed for some installations that require the pilot to confirm functionality of certain flight systems before takeoff. The proposed magniX engine installations are not limited to vehicles that will not require rotor locking. Section 33.92 prescribes a test that may not include the appropriate criteria to demonstrate sufficient rotor locking capability for these engines; therefore, this special condition is necessary.

    The proposed special condition does not define “reliable” rotor locking but would allow magniX to classify the hazard (major/minor) and assign the appropriate quantitative criteria that meet the safety objectives required by § 33.75.

29. ***Teardown Inspection*:** Proposed special condition No. 29 would require magniX to perform either a teardown evaluation or a non-teardown evaluation based on the criteria provided in proposed special condition no. 29(a) or (b).

    Proposed special condition no. 29(b) includes restrictive criteria for “non-teardown evaluations” to account for electric engines, sub-assemblies, and components that cannot be disassembled without destroying them. Some electrical and electronic components like magniX’s are constructed in an integrated fashion that precludes the possibility of tearing them down without destroying them. Sections 33.55 and 33.93 are not similar requirements because reciprocating and turbine engines can be disassembled for inspection.

30. ***Containment*:** Proposed special condition No. 30 would require the engine to provide containment features that protect against likely hazards from rotating components unless magniX can show, by test or validated analysis, that the margin to rotor burst does not justify the need for containment features. Rotating components in electric engines are typically disks, shafts, bearings, seals, orbiting magnetic components, and the assembled rotor core. However, if the margin to rotor burst does not unconditionally rule out the possibility of a rotor burst, then the condition would require magniX to assume a rotor burst could occur and provide case features that will contain the failed rotors. In addition, magniX must also determine the effects of subsequent damage precipitated by the main rotor failure and characterize any fragments that are released forward or aft of the containment features. The fragment energy levels, trajectories, and size must be documented in the installation manual because the aircraft will need to account for the effects of a rotor failure in the aircraft design. The intent of this special condition is to prevent hazardous engine effects from structural failure of rotating components and the rotating parts that are built into them.

31. ***Operation with a Variable Pitch Propeller or Fan:*** Proposed special condition No. 31 would require magniX to conduct functional demonstrations, including feathering, negative torque, negative thrust, and reverse thrust operations, as applicable, based on the

propeller or fan's variable pitch functions that are planned for use on these electric engines, with a representative propeller. The tests prescribed in §33.95 for engines operating with variable pitch propellers are based on the operating characteristics of turbine engines, which include thrust response times, engine stall, propeller shaft overload, loss of thrust control, and hardware fatigue. The electric engines proposed by magniX have different operating characteristics that substantially affect their susceptibility to these and other potential failures. Since magniX's proposed electric engines may be installed with a variable pitch propeller, the proposed special condition associated with the operation with a variable pitch propeller or fan is necessary.

32. ***General Conduct of Tests*****:** Proposed special condition No. 32 would require magniX to (1) include scheduled maintenance in the engine ICA before certification; (2) include any maintenance, in addition to the scheduled maintenance, that was needed during the test to satisfy the requirement; and (3) conduct any additional tests that the Administrator finds necessary warranted by the test results.

    For example, certification endurance test shortfalls might be caused by omitting some prescribed engine test conditions or from accelerated deterioration of individual parts arising from the need to force the engine to operating conditions that drive the engine above the engine cycle values of the type design. If an engine part fails during a certification test, the entire engine might be subjected to penalty runs with a replacement or newer part design installed on the engine to meet the test requirements. Also, the maintenance performed to replace the part so that the engine could complete the test would be included in the engine ICA. In another example, if the applicant replaces a part before completing an engine certification test because of a test facility failure and can substantiate the part to the Administrator through bench testing, they might not need to substantiate the part design using penalty runs with the entire engine.

    The term "excessive" is used to describe the frequency of unplanned engine maintenance and the frequency unplanned test stoppages to address engine issues that prevent the engine from completing the tests in proposed special condition nos. 32(b)(1) and (2), respectively. Excessive frequency is an objective assessment from the FAA's analysis of the amount of unplanned maintenance needed for an engine to complete a certification test. The FAA's assessment may include the reasons for the unplanned maintenance, such as the effects test facility equipment may have on the engine, the inability to simulate a realistic engine operating environment, and the extent to which an engine requires modifications to complete a certification the test. In some cases, the applicant may be able to show that unplanned maintenance has no effect on the certification test results, or they might be able to attribute the problem to the facility or test-enabling equipment that is not part of the type design. In these cases, the ICA will not be affected. However, if magniX cannot reconcile the amount of unplanned service, then the FAA may consider the unplanned maintenance required during the certification test to be "excessive," prompting the need to add the unplanned maintenance to mandatory ICA to comply with the certification requirements.

3.2 Background on ASTM F3338, "Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft"

As with many recent ASTM Specifications within the general aviation sphere of influence, ASTM F3338-20, "Standard Specification for Design of Electric Propulsion Units for General

Aviation Aircraft," traces its origins to 14 CFR 33, "Airworthiness Standards: Aircraft Engines." Unlike many of its contemporary ASTM Specifications, the original release, F3338-18, has not fully transmuted into the format of a means of compliance and, therefore, contained much of the same language found in 14 CFR 33. As a result, ASTM WK67455 was established as a working group almost immediately after the initial approval of F3338 to extract the regulatory content from F3338-18 and incorporate suggested improvements, including the addition of a liquid cooling means of compliance. This work effort is reflected in the updated F3338-20.

Given the performance-based tone of the magniX special conditions, the F3338 specification becomes highly complementary to the special conditions, which is an objective many, both in industry and the various certification authorities, have sought to accomplish.

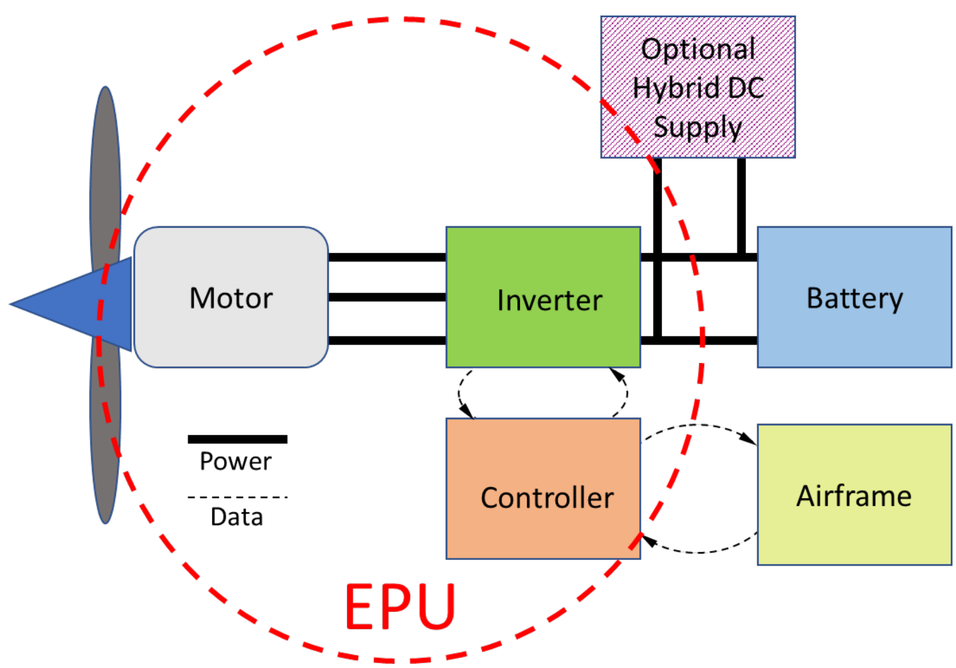
One fundamental assumption made in both the magniX special conditions and F3338 is the consideration of the electric motor and the motor controller as an inseparable pairing. As noted in F3338-20, the motor inverter and the motor controller are typically physically integrated into a single package. Therefore, in this text, the term controller will refer to either or both.

It is generally recognized in the industry that the controller- Permanent Magnet Motor (PMM) interfaces are complex and highly technical, which can significantly influence the durability-related aspects of both the converter and the motor.

Figure 8 depicts the Electric Motor Propulsion Systems (EMPS) architecture assumed throughout this report. Note that Electric Propulsion Unit (EPU) is a term used throughout ASTM F3338.

It should be noted that the guidance in this report is only a starting point. The assigned FAA Aircraft Certification Office (ACO) Project Manager is the final authority as communicated through approved Certification Test Plans as defined in the Project Specific Certification Plan (PSCP).

Figure 8. Electric Motor Propulsion Systems Architecture



As proposed, special condition No. 1 would require magniX to comply with 14 CFR part 33, except for those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines, this section is divided into a first section listing relevant 14 CFR 33 regulations, followed by the special conditions.

A reference to the Means of Compliance from the ASTM F3338, "Design of Electric Propulsion Units for General Aviation Aircraft" is shown.

For each certification basis in each of the Subparts, an assessment was made and color-coded as to NASA's X-57 flight demonstrator to meet:

- Green (ASTM): the means of compliance and methods of compliance associated with existing Standard Specifications and Standard Practices ASTM F39.
- Grey (Special Condition): the means of compliance and methods of compliance under the magniX Special Condition and the associated Standard Specifications and Standard Practices ASTM F39.
- Yellow: If such standards do not exist or are not appropriate, an equivalent means and-or methods of compliance from appropriate FAA Advisory Circulars and other sources are suggested.
- Red: If no appropriate certification rule, means of compliance, and-or method of compliance exists, highlight this omission and provide recommendations.
- Grey: If the certification basis is not applicable to the X-57.

A summary of the distribution of the assessments of the certification basis by Subpart for Aircraft Engines is shown below. The combination means of compliance leveraging the magniX special conditions and the applicable Part 33 reduces the number of uncertain standards considerably and provides for the X-57 to focus on contributing to those standards needing the most attention, such as block testing of electric engines.

	GREEN (ASTM)	GREY (SPECIAL COND.)	YELLOW	RED	GREY
SUBPART A—GENERAL	34%	65%	0%	0%	1%
SUBPART B—DESIGN AND CONSTRUCTION; GENERAL	8%	70%	11%	0%	12%
SUBPART C—DESIGN AND CONSTRUCTION; RECIPROCATING AIRCRAFT ENGINES	***Not Addressed based on magniX Special Condition 1, and in combination with earlier findings presented by HS Advance Concepts team.***				
SUBPART D—BLOCK TESTS; RECIPROCATING AIRCRAFT ENGINES					
SUBPART E—DESIGN AND CONSTRUCTION; TURBINE AIRCRAFT ENGINES					
SUBPART F—BLOCK TESTS; TURBINE AIRCRAFT ENGINES	28%	24%	1%	18%	29%
SUBPART G—SPECIAL REQUIREMENTS: TURBINE AIRCRAFT ENGINES	***Not Addressed based on magniX Special Condition 1, and in combination with earlier findings presented by HS Advance Concepts team.***				
APPENDIX A	97%	0%	0%	0%	3%

A summary of the distribution of the assessments of the certification basis for magniX Special Condition is shown below.

	GREEN (ASTM)	YELLOW	RED	GREY
ALL MAGNIX SPECIAL CONDITIONS	78%	13%	3%	6%

Of the 32 magniX special conditions, 25 apply to the X-57. Two special conditions do not apply to the X-57: 8. Accessory Attachments, and 19. Liquid Systems. Four special conditions for which an alternative MOC is more appropriate: 15. Power Response; 22. Calibration Assurance; 24. Temperature Limit; and 26. Durability Demonstration. There is one special condition to which the X-57 can directly contribute, and that is: 23. Endurance Demonstration.

In general, the application of standards based on the ASTM Standard ASTM F3338, "Design of Electric Propulsion Units for General Aviation Aircraft," aligned with the magniX special conditions and applied to the X-57.

For each of the following sections, an introduction will describe the unique aspect of the X-57 and an overview of the applicability.

3.3 Subpart A, General

3.3.1 Unique Aspects of X-57 to This Subpart

Subpart A of 14 CFR 33 addresses the general airworthiness standards for the issue of type certificates and changes to those certificates. As described earlier, the new and novel features of the magniX EPUs led to the decision to produce a unique set of special conditions which are quite applicable to the X-57.

While many requirements of Subpart A remain applicable, it was determined that the importation or cross-reference to ASTM F3338-20 is appropriate in sections specific to the establishment of power ratings and operating limitations. ASTM F3338-20 appropriately borrowed EPU-specific ratings from IEC 60034-1, Rotating electric machines - Part 1: Rating and performance.

Appendix A to Part 33 – "Instructions for Continued Airworthiness," is addressed in Section 3.8.

3.3.2 magniX Special Conditions

magniX Special Conditions	**Notes**
1. Applicability. Unless otherwise noted in these special conditions, the design must comply with the airworthiness standards for aircraft engines set forth in 14 CFR part 33, except those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.0 and portions of 14 CFR 33 Subpart A listed in Section 3.1.3.]

magniX Special Conditions	**Notes**
2. Engine ratings and operating limits. In addition to § 33.7(a), the design must comply with the following: Ratings and operating limitations must be established and included in the type certificate data sheet based on: (a) Power, torque, speed, and time for: (1) Rated maximum continuous power; and (2) Rated maximum temporary power and associated time limit. (b) The duty cycle and the rating at that duty cycle. The manufacturer must declare the duty cycle or cycles in the engine certificate data sheet.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.3 and portions of 14 CFR 33 Subpart A listed in Section 3.1.3.]

3.3.3 Certification Basis

Subpart A—General	**Notes**
§33.1 Applicability.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.0]
(a) This part prescribes airworthiness standards for the issue of type certificates and changes to those certificates, for aircraft engines.	*Applies to X-57.*
(b) Each person who applies under part 21 for such a certificate or change must show compliance with the applicable requirements of this part and the applicable requirements of part 34 of this chapter. [ref: Amendment 33-7, 41 FR 55474, Dec. 20, 1976, as amended by Amendment 33-14, 55 FR 32861, Aug. 10, 1990]	*Applies to X-57.*
§33.3 General.	*Applies to X-57.*
Each applicant must show that the aircraft engine concerned meets the applicable requirements of this part.	*Applies to X-57.*
§33.4 Instructions for Continued Airworthiness.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.1]
The applicant must prepare Instructions for Continued Airworthiness in accordance with appendix A to this part that are acceptable to the Administrator. The instructions may be incomplete at type certification if a program exists to ensure their completion prior to delivery of the first aircraft with the engine installed, or upon issuance of a standard certificate of airworthiness for the aircraft with the engine installed, whichever occurs later. [ref: Amendment 33-9, 45 FR 60181, Sept. 11, 1980]	*Applies to X-57.*
§33.5 Instruction manual for installing and operating the engine.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.2]
Each applicant must prepare and make available to the Administrator 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. The instructions must include at least the following:	*Applies to X-57.*
(a) Installation instructions. (1) The location of engine mounting attachments, the method of attaching the engine to the aircraft, and the maximum allowable load for the mounting attachments and related structure.	*Applies to X-57.*
(2) The location and description of engine connections to be attached to accessories, pipes, wires, cables, ducts, and cowling.	*Applies to X-57.*
(3) An outline drawing of the engine including overall dimensions.	*Applies to X-57.*
(4) A definition of the physical and functional interfaces with the aircraft and aircraft equipment, including the propeller when applicable.	*Applies to X-57.*
(5) Where an engine system relies on components that are not part of the engine type design, the interface conditions and reliability requirements for those components upon which engine type certification is based must be specified in the engine installation instructions directly or by reference to appropriate documentation.	*Applies to X-57.*
(6) A list of the instruments necessary for control of the engine, including the overall limits of accuracy and transient response required of such instruments for control of the operation of the engine, must also be stated so that the suitability of the instruments as installed may be assessed.	*Applies to X-57.*
(b) Operation instructions. (1) The operating limitations established by the Administrator.	*Applies to X-57.*
(2) The power or thrust ratings and procedures for correcting for nonstandard atmosphere.	*Applies to X-57.*

Subpart A—General	Notes
(3) The recommended procedures, under normal and extreme ambient conditions for—	*Applies to X-57.*
(i) Starting;	*Applies to X-57.*
(ii) Operating on the ground; and	*Applies to X-57.*
(iii) Operating during flight.	*Applies to X-57.*
(4) For rotorcraft engines having one or more OEI ratings, applicants must provide data on engine performance characteristics and variability to enable the aircraft manufacturer to establish aircraft power assurance procedures.	*Removed* [Not applicable]
(5) A description of the primary and all alternate modes, and any back-up system, together with any associated limitations, of the engine control system and its interface with the aircraft systems, including the propeller when applicable.	*Applies to X-57.*
(c) Safety analysis assumptions. The assumptions of the safety analysis as described in §33.75(d) with respect to the reliability of safety devices, instrumentation, early warning devices, maintenance checks, and similar equipment or procedures that are outside the control of the engine manufacturer. [ref: Amendment 33-6, 39 FR 35463, Oct. 1, 1974, as amended by Amendment 33-9, 45 FR 60181, Sept. 11, 1980; Amendment 33-24, 47 FR 50867, Sept. 4, 2007; Amendment 33-25, 73 FR 48123, Aug. 18, 2008; Amendment 33-26, 73 FR 48284, Aug. 19, 2008]	*Applies to X-57.*
§33.7 Engine ratings and operating limitations.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.3]. See special condition 2 in Section 3.1.2.
(a) Engine ratings and operating limitations are established by the Administrator and 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 in this section, as applicable, and any other information found necessary for safe operation of the engine.	*Applies to X-57.* . [Reference ASTM F3338-20 Section 5.3]
(b) For reciprocating engines, ratings and operating limitations are established relating to the following:	*Replaced by magniX special condition 2.*
(1) Horsepower or torque, r.p.m., manifold pressure, and time at critical pressure altitude and sea level pressure altitude for—	*Replaced by magniX special condition 2.* . [Reference ASTM F3338-20 Section 5.3]
(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).	
(2) Fuel grade or specification.	
(3) Oil grade or specification.	
(4) **Temperature** of the—	
(i) Cylinder;	
(ii) Oil at the oil inlet; and	
(iii) Turbosupercharger turbine wheel inlet gas.	
(5) Pressure of—	
(i) Fuel at the fuel inlet; and	
(ii) Oil at the main oil gallery.	
(6) Accessory drive torque and overhang moment.	
(7) Component life.	
(8) Turbosupercharger turbine wheel r.p.m.	
(c) For engine, ratings and operating limitations are established relating to the following:	
(1) Horsepower, torque, or thrust, r.p.m., gas temperature, and time for—	
(i) Rated maximum continuous power or thrust (augmented);	
(ii) Rated maximum continuous power or thrust (unaugmented);	
(iii) Rated takeoff power or thrust (augmented);	
(iv) Rated takeoff power or thrust (unaugmented);	
(v) Rated 30-minute OEI power;	
(vi) Rated 21⁄2 -minute OEI power;	
(vii) Rated continuous OEI power; and	
(viii) Rated 2-minute OEI Power;	
(ix) Rated 30-second OEI power; and	
(x) Auxiliary power unit (APU) mode of operation.	

Subpart A—General	Notes
(2) Fuel designation or specification.	
(3) Oil grade or specification.	
(4) Hydraulic fluid specification.	
(5) Temperature of—	
(i) Oil at a location specified by the applicant;	
(ii) Induction air at the inlet face of a supersonic engine, including steady state operation and transient over-temperature and time allowed;	
(iii) Hydraulic fluid of a supersonic engine;	
(iv) Fuel at a location specified by the applicant; and	
(v) External surfaces of the engine, if specified by the applicant.	
(6) Pressure of—	
(i) Fuel at the fuel inlet;	
(ii) Oil at a location specified by the applicant;	
(iii) Induction air at the inlet face of a supersonic engine, including steady state operation and transient overpressure and time allowed; and	
(iv) Hydraulic fluid.	
(7) Accessory drive torque and overhang moment.	
(8) Component life.	
(9) Fuel filtration.	
(10) Oil filtration.	
(11) Bleed air.	
(12) The number of start-stop stress cycles approved for each rotor disc and spacer.	
(13) Inlet air distortion at the engine inlet.	
(14) Transient rotor shaft overspeed r.p.m., and number of overspeed occurrences.	
(15) Transient gas overtemperature, and number of overtemperature occurrences.	
(16) Transient engine overtorque, and number of overtorque occurrences.	
(17) Maximum engine overtorque for turbopropeller and turboshaft engines incorporating free power turbines.	
(18) For engines to be used in supersonic aircraft, engine rotor windmilling rotational r.p.m.	
(d) In determining the engine performance and operating limitations, the overall limits of accuracy of the engine control system and of the necessary instrumentation as defined in §33.5(a)(6) must be taken into account. [ref: Amendment 33-6, 39 FR 35463, Oct. 1, 1974, as amended by Amendment 33-10, 49 FR 6850, Feb. 23, 1984; Amendment 33-11, 51 FR 10346, Mar. 25, 1986; Amendment 33-12, 53 FR 34220, Sept. 2, 1988; Amendment 33-18, 61 FR 31328, June 19, 1996; Amendment 33-26, 73 FR 48284, Aug. 19, 2008; Amendment 33-30, 74 FR 45310, Sept. 2, 2009]	*Applies to X-57.*
§33.8 Selection of engine power and thrust ratings.	*Modified.* [The insertion of ASTM F3338-20 Sections 5.3.5 through 5.3.8 is recommended.]
(a) Requested engine power and thrust ratings must be selected by the applicant.	
(b) Each 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. [ref: Amendment 33-3, 32 FR 3736, Mar. 4, 1967]	

3.3.4 ASTM F3338-20, Specification for Design of Electric Propulsion Units for General Aviation Aircraft, §§5.1 and 5.2

The following sections of F3338 "Specification for Design of Electric Propulsion Units for General Aviation Aircraft," §5.1, Instructions for Continued Airworthiness; and §5.2 Instruction Manual for Installing and Operating the EPU, are reviewed below.

F3338 - Standard Specification for Design of EPUs for General Aviation Aircraft	Comment
5.1 Instructions for Continued Airworthiness:	Listed for reference only.
5.1.1 Instructions for continued airworthiness must be prepared. The instructions may be incomplete at the time of certification or approval:	
5.1.1.1 If a program exists to ensure their completion prior to delivery of the first aircraft with the EPU installed, or	
5.1.1.2 Upon CAA approval for the aircraft with the EPU installed, whichever occurs later.	

F3338 - Standard Specification for Design of EPUs for General Aviation Aircraft	**Comment**
5.1.2 A maintenance manual shall be provided that defines maintenance requirements for the continued airworthiness of the EPU, such as periodic installed, major inspections, repairs, replacement or overhaul intervals, and any other maintenance limitations including limited life components requiring replacement between overhaul intervals. Maintenance requirements for the continued airworthiness of the EPU also includes special equipment or testing required to ensure the electrical propulsion system is safe to continued operation.	
5.1.3 If applicable, an overhaul manual that provides instructions for disassembling, replacing, or overhauling components identified in the manual for such, in order to return the EPU to airworthy condition that is safe for operation until the next major overhaul.	
5.1.4 Updates to the Instructions for Continued Airworthiness must be made available by the EPU manufacturer or other responsible party such that those instructions remain current.	
5.2 Instruction Manual for Installing and Operating the EPU:	
5.2.1 Instructions for installing and operating the EPU must be made available to the CAA as part of the certification process and to the customer at the time of delivery of the EPU. The instructions must include directly, or by reference to appropriate documentation, at least the following:	
5.2.1.1 Installation Instructions—Coordination is recommended between the EPU manufacturer and the installer. However, if the installer is not identified at the time of EPU design, the following aspects still need definition in the installation instructions.	
(1) An outline drawing of the EPU including overall dimensions.	
(2) A definition of the physical and functional interfaces of all elements of the EPU, with the aircraft and aircraft equipment, including the propeller or fan, when applicable. Including the location and description of EPU connections for attachment of accessories, wires, cables, cooling ducts, cowling, and any other equipment attached to the EPU.	
(3) Where an EPU system a combination of components, parts, and elements that are interconnected to perform one or more functions. Subcommittee: F39.03 Standard: F3153 relies on components that are not part of the EPU type design, the interface conditions and reliability requirements for those components, as used in the safety analysis, must be specified in the EPU installation instructions. If reliability values used in the safety analysis are based on assumptions, these assumed values must be specified in the EPU installation instructions. Requirements for mitigation means, that are not part of the EPU, must be specified in the installation and operation instructions.	
(4) A list of the instruments necessary for the control and operation of the EPU, including the overall limits of accuracy and transient response requirements, must be stated in a manner that allows the satisfactory nature of instruments as installed to be determined. NOTE 1: "Instrument" is used to refer to any device necessary to measure EPU parameters and convey them to the appropriate decision-making center, be that a pilot or software-based control.	
(5) The limits on environmental conditions, including EMI, HIRF, and lightning for which the EPU was designed and qualified.	
5.2.1.2 Operation Instructions:	
(1) The operating limitations established within the showing of compliance.	
(2) The power ratings and procedures for correcting for nonstandard atmosphere.	
(3) The recommended procedures, under normal and critical ambient conditions for:	
(a) Powering on;	
(b) Operating on the ground;	
(c) Operating during flight.	
(4) A description of the primary and all alternate modes, and any back-up system, together with any associated limitations, of the EPU control system and its interface with the aircraft systems, including the propeller or fan if these are integral with the EPU.	
5.3 EPU Operating Limitations and Ratings:	*Reference 14 CFR 33.7 in Section 3.1.3, above.*
5.3.1 Ratings and operating limitations are established by the administrator and included in the product certificate data sheet, including ratings and limitations based on the operating conditions and information specified in this section, as applicable, and any other information found necessary for safe operation of the engine.	
5.3.2 EPU operating limitations are established as applicable, including:	
5.3.2.1 Maximum transient rotor shaft overspeed and time;	
5.3.2.2 Maximum transient EPU overtorque and time, and number of overtorque occurrences;	
5.3.2.3 Maximum EPU overtorque and time;	
5.3.2.4 Electrical power, voltage, current, frequency, and electrical power quality limits;	
5.3.2.5 Maximum rated temperature;	

F3338 - Standard Specification for Design of EPUs for General Aviation Aircraft	Comment
5.3.2.6 Maximum and minimum continuous temperature, current, voltage;	
5.3.2.7 Vibration limits; and	
5.3.2.8 Any other information necessary for safe operation of the EPU.	
5.3.3 EPU ratings are established, as applicable, and are based on the intended duty cycle and the assignment of ratings as defined below, including:	
5.3.3.1 Power, torque, speed, and time for:	
(1) Rated maximum continuous power, and	
(2) Rated maximum temporary power and associated time limit.	
5.3.4 Duty Cycle:	
5.3.4.1 Declaration of Duty—The intended duty cycle of the EPU sets the framework for establishment of the ratings. There are a number of typical duty cycles used for electric motors. (See IEC 60034-1.) As the duty cycle combined with the rating at that duty cycle establishes the capability and the limits for the EPU use, the manufacturer declares the duty cycle or cycles. These can be based on the manufacturer's intended use for the EPU or may be based on the required duty cycle of the installer. As detailed in IEC 60034-1, multiple duties and their associated ratings may be established to address various operational conditions. The duty may be described by one of the following:	
(1) Numerically, where the load does not vary or where it varies in a known manner; or	
(2) As a time sequence graph of the variable quantities; or	
(3) By selecting one of the typical duty types in accordance with IEC 60034-1, Paragraph 4 Duty, that is no less onerous than the expected duty.	
5.3.5 Assignment of Rating—The rating, as defined by "set of rated values and operating conditions," shall be assigned by the manufacturer. In assigning the rating, the manufacturer shall select one of the classes of rating as defined in the IEC 60034-1 Paragraph 5 Ratings.	
5.3.6 Motor Rate Output—The rated output is the mechanical power available at the shaft and shall be expressed in watts (W). NOTE 2: It is the practice in some countries for the mechanical power available at the shafts of motors to be expressed in horsepower (1 hp is equivalent to 745,7 W; 1 ch (cheval or metric horsepower) is equivalent to 736 W).	
5.3.7 Machines with More Than One Rating—For machines with more than one rating, the machine shall comply with this specification in all respects at each rating. For multi-speed machines, a rating shall be assigned for each speed. When a rated quantity (output, voltage, speed, etc.) may assume several values or vary continuously within two limits, the rating shall be stated at these values or limits.	
5.3.8 Each selected rating must be for the lowest power that all EPUs of the same type may be expected to produce under the conditions used to determine that rating at all times between overhaul periods or other maintenance.	

3.4 Subpart B, Design and Construction; General

3.4.1 Unique Aspects of X-57 to This Subpart

Subpart B of 14 CFR 33 addresses the general design and construction requirements for reciprocating and turbine aircraft engines. While many requirements of Subpart B remain applicable, this Subpart has also been addressed by the proposed magniX special conditions. Cross-reference to ASTM F3338-20 is appropriate in specific sections as listed below.

The magniX special conditions recognize the unique aspects of EPU systems. Drawing from our experience, the following paragraphs highlight areas worthy of specific consideration.

- Use of commercial, off-the-shelf rolling element bearings. Unlike contemporary aircraft engines, electric motors typically rely on rolling element bearings with integrated environment seals which could be considered in place of traditional bearing seals. A certification plan must include the appropriate environmental tests as extracted from RTCA DO-160-E. These bearings are likely to be grease-packed bearings requiring periodic inspection for adequate quantities of grease.
- The addition of a brushless direct current (DC) motor implies the presence of permanent magnets within rotating elements of the electric motor rotor. In the event of a structural

failure of the magnet retention system, these magnets can become high velocity fragments. In the specific case of an internal rotor electric motor, containment is generally provided by the motor stator structure. However, in this case, magnet fragments can severely damage the stator windings leading to the potential for electric phase shorting or grounding. In the circumstance of external motor rotors, magnet fragments can impact the external case of the motor. Magnet retention system failures can also lead to high levels of vibration while the rotor system is still rotating.
It should be noted that the high lift motors of the internal rotor type and the wingtip propulsive motors are of the external rotor type.

- In the circumstance of ASTM F3338-20, Section 5.9, EPU Rotor Overspeed, we are confused by the over layering of references to the IEC specifications and recommend that the requirements of 14 CFR 33.27 generally remain in place except for requirements that are clearly unique to turbochargers and turbine engines.
- Unlike an internal combustion engine, electric motors and their drives are typically speed restricted by virtue of the fundamental frequency of their converter. However, overspeed can be induced through windmilling torques applied to a fan rotor or propeller. Motor/converter failure modes involving a loss of impedance/drive signal on the motor leads, especially when exacerbated by a partially demagnetized motor rotor, can lead to overspeed conditions.
- Rotor overspeed, especially in an internal rotor type motor, which leads to rotor growth will typically result in an out of balance condition. As a result, it is appropriate to leave some prescriptive elements of the regulation in place.
- Several elements of 14 CFR 33.28 were not carried over into ASTM F3338-20 and we feel they should remain in place, namely;
    - Elimination of the OEI ratings and their accompanying requirements.
    - Acknowledgement of the presence and requisite special treatment of programmable logic devices using digital logic or other complex design technologies.
    - Deleted requirement to assess the possibility and subsequent effect of incorrect fit of instruments, sensors, or connectors.
    - Dropped requirement to monitor vibration levels in high speed rotor systems.

3.4.2 magniX Special Conditions

magniX Special Conditions	
3. Materials. The engine design must comply with 14 CFR 33.15.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.4 and portions of 14 CFR 33 Subpart B listed in Section 3.2.3.]
4. Fire protection. The engine design must comply with 14 CFR 33.17. In addition, high-voltage electrical wiring interconnect systems must be protected against arc-faults. Any non-protected electrical wiring interconnects must be analyzed to show that arc-faults do not cause a hazardous engine effect.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.5 and portions of 14 CFR 33 Subpart B listed in Section 3.2.3.]
5. Durability. The engine design and construction must minimize the development of an unsafe condition of the engine between maintenance intervals, overhaul periods, or mandatory actions described in the applicable Instructions for Continued Airworthiness (ICA).	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.6.]

magniX Special Conditions	
6. Engine cooling. The engine design and construction must comply with 14 CFR 33.21. In addition, if cooling is required to satisfy the safety analysis as described in special condition no. 17, the cooling system monitoring features and usage must be documented in the engine installation manual.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.7 and portions of 14 CFR 33 Subpart B listed in Section 3.2.3.]
7. Engine mounting attachments and structure. The engine mounting attachments and related engine structure must comply with 14 CFR 33.23.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.8 and portions of 14 CFR 33 Subpart B listed in Section 3.2.3.]
8. Accessory attachments. The engine must comply with 14 CFR 33.25.	*Does not apply to X-57.*
9. Overspeed. (a) A rotor overspeed must not result in a burst, rotor growth, or damage that results in a hazardous engine effect, as defined in special condition no. 17(d)(2). Compliance with this paragraph must be shown by test, validated analysis, or a combination of both. Applicable assumed speeds must be declared and justified. (b) Rotors must possess sufficient strength with a margin to burst above certified operating conditions and above failure conditions leading to rotor overspeed. The margin to burst must be shown by tests, validated analysis, or a combination of both. (c) The engine must not exceed the speed operational limitations that could affect rotor structural integrity.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.9 and portions of 14 CFR 33 Subpart B listed in Section 3.2.3.]

10. Engine control systems.

(a) Applicability.

The requirements of this paragraph apply to any system or device that controls, limits, monitors, or protects engine operation and is necessary for the continued airworthiness of the engine.

(b) Engine control.

The engine control system must ensure the engine does not experience any unacceptable operating characteristics or exceed any of its operating limitations.

(c) Design assurance.

The software and complex electronic hardware, including programmable logic devices, must be —

(1) Designed and developed using a structured and systematic approach that provides a level of assurance for the logic commensurate with the hazard associated with the failure or malfunction of the systems in which the devices are located; and

(2) Substantiated by a verification methodology acceptable to the Administrator.

(d) Validation.

All functional aspects of the control system must be substantiated by tests, analysis, or a combination thereof, to show that the engine control system performs the intended functions throughout the declared operational envelope.

(e) Environmental limits.

Environmental limits that cannot be adequately substantiated by endurance demonstrations, validated analysis, or a combination thereof, must be demonstrated by the system and component tests in special condition no. 27.

(f) Engine control system failures.

The engine control system must—

(1) Have a maximum rate of Loss of Power Control (LOPC) that is suitable for the intended application;

(2) When in the full-up configuration, be single-fault tolerant, as determined by the Administrator, for electrical, electrically detectable, and electronic failures involving LOPC events;

(3) Not have any single failure that result in hazardous engine effects; and

(4) Not have any likely failure or malfunction that lead to local events in the intended aircraft installation.

(g) System safety assessment.

This assessment must identify faults or failures that affect normal operation, together with the predicted frequency of occurrence of these faults or failures.

(h) Protection systems.

The design and function of the engine control devices and systems, together with engine instruments, operating instructions and maintenance instructions, must ensure that engine operating limitations will not be exceeded in-service.

(i) Aircraft-supplied data.

Any single failure leading to loss, interruption, or corruption of aircraft-supplied data (other than power command signals from the aircraft), or aircraft-supplied data shared between engine systems within a single engine or between fully independent engine systems must—

(1) Not result in a hazardous engine effect, as defined in special condition no. 17(d)(2), for any engine installed on the aircraft; and

(2) Be able to be detected and accommodated by the control system.

(j) Engine control system electrical power.

The engine control system must be designed such that the loss, malfunction, or interruption of the control system electrical power source will not result in a hazardous engine effect, as defined in special condition no. 17(d)(2), the unacceptable transmission of erroneous data, or continued engine operation in the absence of the control function.

Applies to X-57. [Reference ASTM F3338-20 Section 5.10.].

magniX Special Conditions	
11. Instrument connection. The applicant must comply with 14 CFR 33.29(a), (e), (f), and (g). In addition, as part of the system safety assessment of special condition no. 10(g), the applicant must assess the possibility and subsequent effect of incorrect fit of instruments, sensors, or connectors. Where practicable, the applicant must take design precautions to prevent incorrect configuration of the system.	Applies to X-57. [Reference ASTM F3338-20 Section 5.11 and portions of 14 CFR 33 Subpart B listed in Section 3.2.3.]

3.4.3 Certification Basis

Subpart B—Design and Construction; General	**Notes**
§33.11 Applicability.	*Superseded by the magniX special conditions.*
This subpart prescribes the general design and construction requirements for reciprocating and turbine aircraft engines.	
§33.13 [Reserved]	
§33.15 Materials.	*Applies to X-57.* [We find ASTM F3338-20, Section 5.4.2 to be adequate as a supplementary MoC as it stresses the importance of addressing electrical systems design properties and corrosion. A certification plan must include the appropriate environmental tests as extracted from RTCA DO-160-E Sections 4, 6, 10, 11, 12, 13 and 14. See magniX special condition 3.]
The suitability and durability of materials used in the engine must—	
(a) Be established on the basis of experience or tests; and	
(b) Conform to approved specifications (such as industry or military specifications) that ensure their having the strength and other properties assumed in the design data. (Secs. 313(a), 601, and 603, 72 Stat. 759, 775, 49 U.S.C. 1354(a), 1421, and 1423; sec. 6(c), 49 U.S.C. 1655(c)) [ref: Amendment 33-8, 42 FR 15047, Mar. 17, 1977, as amended by Amendment 33-10, 49 FR 6850, Feb. 23, 1984]	
§33.17 Fire protection.	*Applies to X-57.* [Reference magniX special condition 4. Reference ASTM F3338-20 Section 5.5. Like the special condition, this section of ASTM F3338-20 recognizes the potential for the presence of flammable fluids in fire zones. In addition, neither this Regulation, AC 33.17-1A, or ASTM F3338-20 Section 5.5 is a complete treatment of the compliance standards likely to be required for an EPU. Given the evolution in technology, individual MoCs will likely be required on a project-by-project basis until such time as more uniform EPU architecture patterns emerge.]
(a) The design and construction of the engine and the materials used must minimize the probability of the occurrence and spread of fire during normal operation and failure conditions, and must minimize the effect of such a fire. In addition, the design and construction of turbine engines must minimize the probability of the occurrence of an internal fire that could result in structural failure or other hazardous effects.	
(b) Except as provided in paragraph (c) of this section, each external line, fitting, and other component, which contains or conveys flammable fluid during normal engine operation, must be fire resistant or fireproof, as determined by the Administrator. Components must be shielded or located to safeguard against the ignition of leaking flammable fluid.	
(c) A tank, which contains flammable fluids and any associated shut-off means and supports, which are part of and attached to the engine, must be fireproof either by construction or by protection unless damage by fire will not cause leakage or spillage of a hazardous quantity of flammable fluid. For a reciprocating engine having an integral oil sump of less than 23.7 liters capacity, the oil sump need not be fireproof or enclosed by a fireproof shield.	
(d) An engine component designed, constructed, and installed to act as a firewall must be:	
(1) Fireproof;	
(2) Constructed so that no hazardous quantity of air, fluid or flame can pass around or through the firewall; and,	
(3) Protected against corrosion;	
(e) In addition to the requirements of paragraphs (a) and (b) of this section, engine control system components that are located in a designated fire zone must be fire resistant or fireproof, as determined by the Administrator.	

Subpart B—Design and Construction; General	**Notes**
(f) Unintentional accumulation of hazardous quantities of flammable fluid within the engine must be prevented by draining and venting.	
(g) Any components, modules, or equipment, which are susceptible to or are potential sources of static discharges or electrical fault currents must be designed and constructed to be properly grounded to the engine reference, to minimize the risk of ignition in external areas where flammable fluids or vapors could be present. [ref: Doc. No. FAA-2007-28503, 74 FR 37930, July 30, 2009]	
§33.19 Durability.	*Unchanged*
(a) Engine design and construction must minimize the development of an unsafe condition of the engine between overhaul periods. The design of the motor rotor cases must provide for the containment of damage from rotor magnet retention system failure. Energy levels and trajectories of fragments resulting from rotor magnet retention system failure that lie outside the motor cases must be defined.	*Modified.* [The addition of a brushless DC motor implies the presence of permanent magnets within rotating elements of the electric motor rotor. Reference magniX special condition 5. ASTM F3338-20, Section 5.6 lacks the specificity to be a robust MoC.]
(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 of this chapter. [ref: Doc. No. 3025, 29 FR 7453, June 10, 1964, as amended by Amendment 33-9, 45 FR 60181, Sept. 11, 1980; Amendment 33-10, 49 FR 6851, Feb. 23, 1984; Amendment 33-28, 73 FR 63346, Oct. 24, 2008]	
§33.21 Engine cooling.	*Applies to X-57.* [Reference magniX special condition 6. Reliance on ASTM F3338-20 Section 5.7 is acceptable.]
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.	*Applies to X-57.* [Reference magniX special condition 7. ASTM F3338-20 Section 5.8 is largely redundant. However, Section 5.8.3 should be changed to reflect that a source of ignition also needs to be present in the compartment.]
(a) The maximum allowable limit and ultimate loads for engine mounting attachments and related engine structure must be specified.	
(b) The engine mounting attachments and related engine structure must be able to withstand—	
(1) The specified limit loads without permanent deformation; and	
(2) The specified ultimate loads without failure, but may exhibit permanent deformation. [ref: Amendment 33-10, 49 FR 6851, Feb. 23, 1984]	
§33.25 Accessory attachments.	*Does not apply to X-57.* [Reference magniX special condition 8. No equivalent section exists in ASTM F3338-20. While, admittedly, the existence of external accessory drives on an EPU motor or gearbox is unlikely, it could emerge as design feature. Therefore, we recommend leaving this regulation in place.]
The engine must operate properly with the accessory drive and mounting attachments loaded. Each engine accessory drive and mounting attachment must include provisions for sealing to prevent contamination of, or unacceptable leakage from, the engine interior. A drive and mounting attachment requiring lubrication for external drive splines, or coupling by engine oil, must include provisions for sealing to prevent unacceptable loss of oil and to prevent contamination from sources outside the chamber enclosing the drive connection. The design of the engine must allow for the examination, adjustment, or removal of each accessory required for engine operation. [ref: Amendment 33-10, 49 FR 6851, Feb. 23, 1984]	
§33.27 Turbine, compressor, fan, and turbosupercharger rotor overspeed.	*Applies to X-57.* [Reference magniX special condition 9. Reliance on ASTM F3338-20 Section 5.9 is acceptable.]
(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.	
(1) Test rotors used to demonstrate compliance with this section that do not have the most adverse combination of material properties and dimensional tolerances must be tested at conditions which have been adjusted to ensure the minimum specification rotor possesses the required overspeed capability. This can be accomplished by increasing test speed, temperature, and/or loads.	
(2) When an engine test is being used to demonstrate compliance with the overspeed conditions listed in paragraph (b)(3) or (b)(4) of this section and the failure of a component or system is sudden and transient, it may not be possible to operate the engine for 5 minutes after the failure. Under these circumstances, the actual overspeed duration is acceptable if the required maximum overspeed is achieved.	

Subpart B—Design and Construction; General	Notes
(b) When determining the maximum overspeed condition applicable to each rotor in order to comply with paragraphs (a) and (c) of this section, the applicant must evaluate the following rotor speeds taking into consideration the part's operating temperatures and temperature gradients throughout the engine's operating envelope:	
(1) 120 percent of the maximum permissible rotor speed associated with any of the engine ratings except one-engine-inoperative (OEI) ratings of less than 2 1⁄2 minutes.	
(2) 115 percent of the maximum permissible rotor speed associated with any OEI ratings of less than 21⁄2 minutes.	
(3) 105 percent of the highest rotor speed that would result from either:	
(i) The failure of the component or system which, in a representative installation of the engine, is the most critical with respect to overspeed when operating at any rating condition except OEI ratings of less than 2 1⁄2 minutes, or	
(ii) The failure of any component or system in a representative installation of the engine, in combination with any other failure of a component or system that would not normally be detected during a routine pre-flight check or during normal flight operation, that is the most critical with respect to overspeed, except as provided by paragraph (c) of this section, when operating at any rating condition except OEI ratings of less than 2 1⁄2 minutes.	
(4) 100 percent of the highest rotor speed that would result from the failure of the component or system which, in a representative installation of the engine, is the most critical with respect to overspeed when operating at any OEI rating of less than 2 1⁄2 minutes.	
(c) The highest overspeed that results from a complete loss of load on a turbine rotor, except as provided by paragraph (f) of this section, must be included in the overspeed conditions considered by paragraphs (b)(3)(i), (b)(3)(ii), and (b)(4) of this section, regardless of whether that overspeed results from a failure within the engine or external to the engine. The overspeed resulting from any other single failure must be considered when selecting the most limiting overspeed conditions applicable to each rotor. Overspeeds resulting from combinations of failures must also be considered unless the applicant can show that the probability of occurrence is not greater than extremely remote (probability range of 10^{-7} to 10^{-9} per engine flight hour).	
(d) In addition, the applicant must demonstrate that each fan, compressor, turbine, and turbosupercharger rotor complies with paragraphs (d)(1) and (d)(2) of this section for the maximum overspeed achieved when subjected to the conditions specified in paragraphs (b)(3) and (b)(4) of this section. The applicant must use the approach in paragraph (a) of this section which specifies the required test conditions.	
(1) Rotor Growth must not cause the engine to:	
(i) Catch fire,	
(ii) Release high-energy debris through the engine casing or result in a hazardous failure of the engine casing,	
(iii) Generate loads greater than those ultimate loads specified in §33.23(a), or	
(iv) Lose the capability of being shut down.	
(2) Following an overspeed event and after continued operation, the rotor may not exhibit conditions such as cracking or distortion which preclude continued safe operation.	
(e) The design and functioning of engine control systems, instruments, and other methods not covered under §33.28 must ensure that the engine operating limitations that affect turbine, compressor, fan and turbosupercharger rotor structural integrity will not be exceeded in service.	
(f) Failure of a shaft section may be excluded from consideration in determining the highest overspeed that would result from a complete loss of load on a turbine rotor if the applicant:	
(1) Identifies the shaft as an engine life-limited-part and complies with §33.70.	
(2) Uses material and design features that are well understood and that can be analyzed by well-established and validated stress analysis techniques.	

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(3) Determines, based on an assessment of the environment surrounding the shaft section, that environmental influences are unlikely to cause a shaft failure. This assessment must include complexity of design, corrosion, wear, vibration, fire, contact with adjacent components or structure, overheating, and secondary effects from other failures or combination of failures.	
(4) Identifies and declares, in accordance with §33.5, any assumptions regarding the engine installation in making the assessment described above in paragraph (f)(3) of this section.	
(5) Assesses, and considers as appropriate, experience with shaft sections of similar design.	
(6) Does not exclude the entire shaft.	
(g) If analysis is used to meet the overspeed requirements, then the analytical tool must be validated to prior overspeed test results of a similar rotor. The tool must be validated for each material. The rotor being certified must not exceed the boundaries of the rotors being used to validate the analytical tool in terms of geometric shape, operating stress, and temperature. Validation includes the ability to accurately predict rotor dimensional growth and the burst speed. The predictions must also show that the rotor being certified does not have lower burst and growth margins than rotors used to validate the tool. [ref: Doc. No. FAA-2010-0398, Amendment 33-31, 76 FR 42023, July 18, 2011]	
§33.28 Engine control systems.	*Applies to X-57.* [We find ASTM F3338-20, Section 5.10 to be adequate as a supplementary MoC. See magniX special condition 10.]
(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. The applicant must substantiate by tests, analysis, or a combination thereof, that the engine control system performs the intended functions in a manner which:	
(i) Enables selected values of relevant control parameters to be maintained and the engine kept within the approved operating limits over changing atmospheric conditions in the declared flight envelope;	
(ii) Complies with the operability requirements of §33.51, 33.65, and 33.73, as appropriate, under all likely system inputs and allowable engine power or thrust demands, unless it can be demonstrated that failure of the control function results in a non-dispatchable condition in the intended application;	
(iii) Allows modulation of engine power or thrust with adequate sensitivity over the declared range of engine operating conditions; and	
(iv) Does not create unacceptable power or thrust oscillations.	
(2) Environmental limits. The applicant must demonstrate, when complying with §33.53 or-33.91, that the engine control system functionality will not be adversely affected by declared environmental conditions, including electromagnetic interference (EMI), High Intensity Radiated Fields (HIRF), and lightning. The limits to which the system has been qualified must be documented in the engine installation instructions.	
(c) Control transitions. (1) The applicant must demonstrate that, when fault or failure results in a change from one control mode to another, from one channel to another, or from the primary system to the back-up system, the change occurs so that:	
(i) The engine does not exceed any of its operating limitations;	
(ii) The engine does not surge, stall, or experience unacceptable thrust of power changes or oscillations or other unacceptable characteristics; and	
(iii) There is a means to alert the flight crew if the crew is required to initiate, respond to, or be aware of the control mode change. The means to alert the crew must be described in the engine installation instructions, and the crew action must be described in the engine operating instructions;	
(2) The magnitude of any change in thrust or power and the associated transition time must be identified and described in the engine installation instructions and the engine operating instructions.	
(d) engine control system failures. The applicant must design and construct the engine control system so that:	

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(1) The rate for Loss of Thrust (or Power) Control (LOTC/LOPC) events, consistent with the safety objective associated with the intended application can be achieved;	
(2) In the full-up configuration, the system is single fault tolerant, as determined by the Administrator, for electrical, or electronic failures with respect to LOTC/LOPC events;	
(3) Single failures of engine control system components do not result in a hazardous engine effect; and	
(4) Foreseeable failures or malfunctions leading to local events in the intended aircraft installation, such as fire, overheat, or failures leading to damage to engine control system components, do not result in a hazardous engine effect due to engine control system failures or malfunctions.	
(e) System safety assessment. When complying with this section and §33.75, the applicant must complete a System Safety Assessment for the engine control system. This assessment must identify faults or failures that result in a change in thrust or power, transmission of erroneous data, or an effect on engine operability producing a surge or stall-together with the predicted frequency of occurrence of these faults or failures.	
(f) Protection systems. (1) The design and functioning of engine control devices and systems, together with engine instruments and operating and maintenance instructions, must provide reasonable assurance that those engine operating limitations that affect turbine, compressor, fan and turbosupercharger rotor structural integrity will not be exceeded in service.	
(2) When electronic overspeed protection systems are provided, the design must include a means for testing, at least once per engine start/stop cycle, to establish the availability of the protection function. The means must be such that a complete test of the system can be achieved in the minimum number of cycles. If the test is not fully automatic, the requirement for a manual test must be contained in the engine instructions for operation.	
(3) When overspeed protection is provided through hydromechanical or mechanical means, the applicant must demonstrate by test or other acceptable means that the overspeed function remains available between inspection and maintenance periods.	
(g) Software. The applicant must design, implement, and verify all associated software to minimize the existence of errors by using a method, approved by the FAA, consistent with the criticality of the performed functions.	
(h) Aircraft-supplied data. Single failures leading to loss, interruption or corruption of aircraft-supplied data (other than thrust or power command signals from the aircraft), or data shared between engines must:	
(1) Not result in a hazardous engine effect for any engine; and	
(2) Be detected and accommodated. The accommodation strategy must not result in an unacceptable change in thrust or power or an unacceptable change in engine operating and starting characteristics. The applicant must evaluate and document in the engine installation instructions the effects of these failures on engine power or thrust, engine operability, and starting characteristics throughout the flight envelope.	
(i) Aircraft-supplied electrical power. (1) The applicant must design engine control system so that the loss, malfunction, or interruption of electrical power supplied from the aircraft to the engine control system will not result in any of the following:	
(i) A hazardous engine effect, or	
(ii) The unacceptable transmission of erroneous data.	
(2) When an engine dedicated power source is required for compliance with paragraph (i)(1) of this section, its capacity should provide sufficient margin to account for engine operation below idle where the engine control system is designed and expected to recover engine operation automatically.	
(3) The applicant must identify and declare the need for, and the characteristics of, any electrical power supplied from the aircraft to the engine control system for starting and operating the engine, including transient and steady state voltage limits, in the engine instructions for installation.	

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(4) Low voltage transients outside the power supply voltage limitations declared in paragraph (i)(3) of this section must meet the requirements of paragraph (i)(1) of this section. The engine control system must be capable of resuming normal operation when aircraft-supplied power returns to within the declared limits.	
(j) Air pressure signal. The applicant must consider the effects of blockage or leakage of the signal lines on the engine control system as part of the System Safety Assessment of paragraph (e) of this section and must adopt the appropriate design precautions.	
(k) Automatic availability and control of engine power for 30-second OEI rating. Rotorcraft engines having a 30-second OEI rating must incorporate a means, or a provision for a means, for automatic availability and automatic control of the 30-second OEI power within its operating limitations.	
(l) engine shut down means. Means must be provided for shutting down the engine rapidly.	
(m) Programmable logic devices. The development of programmable logic devices using digital logic or other complex design technologies must provide a level of assurance for the encoded logic commensurate with the hazard associated with the failure or malfunction of the systems in which the devices are located. The applicant must provide evidence that the development of these devices has been done by using a method, approved by the FAA, that is consistent with the criticality of the performed function. [ref: Amendment 33-26, 73 FR 48284, Aug. 19, 2008]	
§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.	*Applies to X-57.* [See magniX special condition 11.]
(b) A connection must be provided on each turbojet engine for an indicator system to indicate rotor system unbalance.	*Does not apply to X-57.*
(c) Each rotorcraft turbine engine having a 30-second OEI rating and a 2-minute OEI rating must have a means or a provision for a means to:	
(1) Alert the pilot when the engine is at the 30-second OEI and the 2-minute OEI power levels, when the event begins, and when the time interval expires;	
(2) Automatically record each usage and duration of power at the 30-second OEI and 2-minute OEI levels;	
(3) Alert maintenance personnel in a positive manner that the engine has been operated at either or both of the 30-second and 2-minute OEI power levels, and permit retrieval of the recorded data; and	
(4) Enable routine verification of the proper operation of the above means.	
(d) The means, or the provision for a means, of paragraphs (c)(2) and (c)(3) of this section must not be capable of being reset in flight.	
(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.	*Applies to X-57.* [See magniX special condition 11.]
(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.	
(g) The sensors, together with associated wiring and signal conditioning, must be segregated, electrically and physically, to the extent necessary to ensure that the probability of a fault propagating from instrumentation and monitoring functions to control functions, or vice versa, is consistent with the failure effect of the fault.	

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(h) The applicant must provide instrumentation enabling the flight crew to monitor the functioning of the engine cooling system unless appropriate inspections are published in the relevant manuals and evidence shows that:	*Does not apply to X-57.*
(1) Other existing instrumentation provides adequate warning of failure or impending failure;	
(2) Failure of the cooling system would not lead to hazardous engine effects before detection; or	
(3) The probability of failure of the cooling system is extremely remote. [ref: Amendment 33-5, 39 FR 1831, Jan. 15, 1974, as amended by Amendment 33-6, 39 FR 35465, Oct. 1, 1974; Amendment 33-18, 61 FR 31328, June 19, 1996; Amendment 33-25, 73 FR 48123, Aug. 18, 2008; Amendment 33-26, 73 FR 48285, Aug. 19, 2008]	

3.4.4 ASTM F3338-20, Specification for Design of Electric Propulsion Units for General Aviation Aircraft, §§5.3- §5.11

The following sections of F3338-20, "Specification for Design of Electric Propulsion Units for General Aviation Aircraft," §5.3, EPU Operating Limitations and Ratings; §5.4, Materials; §5.5, Fire Protection; §5.6, Durability; §5.7, EPU Cooling; §5.8, EPU Mounting Attachments and Structure; §5.9, EPU Rotor Overspeed; §5.10, EPU Controls; and §5.11, Instrument or Sensor Connection are shown below.

F3338 - Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft	Comment
5.4 Materials:	Listed for reference only
5.4.1 The materials and components used in the EPU must be established on the basis of industry or military specification(s) for the intended design conditions of the system The assumed design values of properties of materials must be suitably related to the minimum properties stated in the material specification. Otherwise, proof of suitability and durability acceptable to the CAA must be established on the basis of tests or other means that ensure their having the strength and other properties assumed in the design data.	
5.4.2 Manufacturing methods and processes must be such as to produce sound structure and mechanisms, and electrical systems that retain the design properties under reasonable service conditions. This includes the effects of corrosion.	
5.5 Fire Protection:	
5.5.1 The design and construction of the EPU and the materials used must minimize the probability of the occurrence and spread of fire during normal operation and EPU failure conditions and must minimize the effect of such a fire. EPU high voltage electrical wiring interconnect systems should be protected against arc-faults. Any nonprotected electrical wiring interconnects should be analyzed to show that arc faults do not cause a hazardous condition. If flammable fluids are used, then this must be stated in any required installation instructions so that consideration may be given (at the aircraft level) to determining if a fire zone must be established under the associated aircraft certification rules.	
5.6 Durability:	
5.6.1 EPU design and construction must minimize the development of an unsafe condition of the EPU between maintenance intervals, removal from service or overhaul periods or mandated life defined the Instructions for Continued Airworthiness, as applicable.	
5.7 EPU Cooling:	
5.7.1 EPU cooling shall be sufficient under all conditions within the declared operational limitations to prevent component temperatures exceeding applicable limits.	
5.7.2 If aspects of the cooling require the installer to ensure that the temperature limits are met, those limits must be specified in the installation manual.	
5.7.3 Instrumentation or sensors shall be provided to enable the flight crew or the automatic control system to monitor the functioning of the EPU cooling system unless appropriate inspections are published in the relevant manuals and evidence shows that:	Listed for reference only
5.7.3.1 Failure of the cooling system would not lead to hazardous EPU effects defined in 3.2.4 before detection; or	

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5.7.3.2 Other existing instrumentation or sensors provides adequate warning of failure or impending failure; or	
5.7.3.3 The probability of failure of the cooling system is extremely remote.	
5.7.4 An EPU with a liquid cooling system shall also meet the applicable requirements of 5.18.	
5.8 EPU Mounting Attachments and Structure:	Listed for reference only
5.8.1 The maximum allowable limit and ultimate load for the integral EPU mounting attachment points and related EPU structure must be specified.	
5.8.2 The EPU mounting attachments and related EPU structure must be able to withstand:	
5.8.2.1 The specified limit loads without permanent deformation; and	
5.8.2.2 The specified ultimate loads without failure but allowing for permanent deformation.	
5.8.3 If flammable fluids are used within the EPU, the mounts and the mounting features must be demonstrated to be fireproof.	
5.9 EPU Rotor Overspeed:	
5.9.1 The rotors must, including any integral fan rotors used for cooling:	
5.9.1.1 Possess sufficient strength with a margin to burst above certified operating conditions and above failure conditions leading to rotor overspeed, and	
5.9.1.2 Do not exhibit a level of growth or damage that could lead to a hazardous EPU effect.	
5.9.2 Burst—For each rotor of the EPU, it must be established by test, analysis, or a combination of both, that each rotor will not burst when subjected to the analysis and test conditions per IEC 60349, Part 4, or an equivalent standard.	
5.9.2.1 Unless otherwise specified in IEC 60349, Part 4, test rotors used to demonstrate compliance with this section that do not have the most adverse combination of material properties and dimensional tolerances must be tested at conditions which have been adjusted to ensure the minimum specification rotor possesses the required overspeed capability. This can be accomplished by increasing test speed, temperature, or loads, or combinations thereof.	
5.9.2.2 When an EPU test is being used to demonstrate compliance with the overspeed conditions listed in 5.9.3 of this section and the failure of a component or system is sudden and transient, it may not be possible to operate the EPU for 5 min after the failure. Under these circumstances, the actual overspeed duration is acceptable if the required maximum overspeed is achieved as required by IEC 60349-4.	
5.9.3 Max Overspeed—When determining the maximum overspeed condition applicable to each rotor in order to comply with 5.9.2 of this section, the evaluation must include the test conditions as specified in IEC 60034-1 and the following:	Listed for reference only
5.9.3.1 One hundred twenty percent of the maximum permissible rotor speed associated with any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.	
5.9.3.2 One hundred fifteen percent of the maximum no-load speed associated with any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.	
5.9.3.3 One hundred five percent of the highest rotor speed that would result from either:	
(1) The failure of the component or system which, in a representative installation of the EPU, is the most critical with respect to overspeed when operating at any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.	
(2) The failure of any component or system in a representative installation of the EPU, in combination with any other failure of a component or system that would not normally be detected during a routine pre-flight check or during normal flight operation, that is the most critical with respect to overspeed, except as provided by paragraph 5.9.4 of this section, when operating at any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.	
5.9.4 Loss of Load—The highest overspeed that results from a complete loss of load on an EPU rotor, must be determined and included in the overspeed conditions considered by 5.9.3 of this section. The complete loss of load must also consider:	
5.9.4.1 Demagnetization in combination with excessive external torque imposed (propeller induced no-load overspeed),	
5.9.4.2 Failures external to the e-motor, and	
5.9.4.3 Combinations of failures unless those combinations can be shown to be extremely remote.	
5.9.5 Growth—In addition, each EPU rotor must comply with 5.9.5.1 and 5.9.5.2 of this section for the maximum overspeed achieved when subjected to the conditions specified in 5.9.3 of this section. It must be established using the approach in 5.9.2 of this section that specifies the required test conditions.	

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5.9.5.1 Rotor growth must not cause the motor operation to lead to a hazardous EPU effect.	
5.9.5.2 Following an overspeed event and after continued operation, the rotor may not exhibit conditions such as cracking or distortion, which preclude continued safe operation.	
5.9.6 Controls—The design and functioning of EPU control systems, instruments, and other methods not covered under 5.10 must ensure that the EPU operating limitations that affect rotor structural integrity will not be exceeded in service.	
5.9.7 Shaft Failure—Failure of a shaft section may be excluded from consideration in determining the highest overspeed that would result from a complete loss of load on a rotor if it can be shown that:	
5.9.7.1 The shaft is identified as an EPU life-limited-part and complies with 5.15.	
5.9.7.2 The EPU uses material and design features that are well understood and that can be analyzed by well-established and validated stress analysis techniques.	Listed for reference only
5.9.7.3 It has been determined, based on an assessment of the environment surrounding the shaft section, that environmental influences are unlikely to cause a shaft failure. This assessment must include complexity of design, corrosion, wear, vibration, fire, contact with adjacent components or structure, overheating, and secondary effects from other failures or combination of failures.	
5.9.7.4 It has been identified and declared, in accordance with 5.2, any assumptions regarding the EPU installation in making the assessment described above in 5.9.7.3 of this section.	
5.9.7.5 It has been assessed, and considered as appropriate, experience with shaft sections of similar design.	
5.9.7.6 The entire shaft has not been excluded.	
5.9.7.7 Rationale is provided that the e-motor electrodynamic principle yields intrinsic safety against uncontrollable overspeed in case of rotor shaft failure.	
5.9.8 Use of Analysis—If analysis is used to meet the overspeed requirements, then the analytical tool must be validated to prior overspeed test results of a similar rotor. The tool must be validated for each material. The rotor being certified must not exceed the boundaries of the rotors being used to validate the analytical tool in terms of geometric shape, operating stress, and temperature. Validation includes the ability to accurately predict rotor dimensional growth and the burst speed. The predictions must also show that the rotor being certified does not have lower burst and growth margins than rotors used to validate the tool.	
5.10 EPU Controls:	Listed for reference only
5.10.1 The software and complex electronic hardware, including programmable logic devices, shall be designed and developed using a structured and methodical approach that provides a level of assurance for the logic, that is commensurate with the hazard associated with the failure or malfunction of the systems in which the devices are located, and is substantiated by a verification methodology acceptable to the CAA.	
5.10.2 Applicability—These requirements are applicable to any system or device that controls, limits, monitors, or protects EPU operation, and is necessary for the continued airworthiness of the EPU. If items that influence the EPU system are outside of the EPU manufacturer's control, the assumptions with respect to the reliability and functionality of these parts must be clearly stated in the safety analysis (see 5.19).	
5.10.3 Validation:	
5.10.3.1 Functional Aspects—It must be substantiated by tests, analysis, or a combination thereof, that the EPU control system performs the intended functions in a manner which:	
(1) Enables selected values of relevant control parameters to be maintained and the EPU kept within the approved operating limits over changing atmospheric conditions in the declared flight envelope;	
(2) Complies with the operability requirements of operation and power response tests, as appropriate, under all likely system inputs and allowable EPU power demands, unless it can be demonstrated that failure of the control function results in a non-dispatchable condition in the intended application;	Listed for reference only
(3) Allows modulation of EPU power with adequate sensitivity over the declared range of EPU operating conditions; and	
(4) Does not create unacceptable power oscillations.	

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5.10.3.2 Environmental Limits—Environmental limits that cannot be adequately substantiated in accordance with endurance testing must be demonstrated, via EPU system and component tests (see 5.13). These tests demonstrate that the EPU control system functionality will not be adversely affected by declared environmental conditions, including electromagnetic interference (EMI), High Intensity Radiated Fields (HIRF), and lightning, when applicable, for the intended use. The limits to which the system has been qualified must be documented in the EPU installation instructions.	
5.10.4 Control Transitions—It must be demonstrated that during both normal operation or as a result of fault or failure, changes in one control mode to another, from one channel to another, or from a primary system to a back-up system a combination of components, parts, and elements that are interconnected to perform one or more functions. Subcommittee: F39.03 Standard: F3153, the change occurs so that:	
5.10.4.1 The EPU does not exceed any of its operating limitations;	
5.10.4.2 The EPU does not experience any unacceptable operating characteristics or transient exceedances of any limit potentially leading to unsafe operating conditions. Such nonacceptable operating characteristics include but are not limited to:	
(1) Field excitation at rotor resonance frequency,	
(2) Electromagnetic lock-up (stall),	
(3) Unacceptable power changes or oscillations, and	
(4) Other unacceptable characteristics, for example, electrical arcs, overspeed, or overtorque.	
5.10.4.3 There is a means to signal the aircraft to take action or monitor the control transition. The means to alert the aircraft must be described in the EPU installation instructions, and the action or monitoring required must be described in the EPU operating instructions.	
5.10.4.4 The magnitude of any change in power and the associated transition time must be identified and described in the EPU installation instructions and the EPU operating instructions.	
5.10.5 EPU Control System Failures—The EPU control system must:	
5.10.5.1 Have a maximum rate of Loss of Power Control (LOPC) events that is consistent with the intended application;	
5.10.5.2 Be, in the full-up configuration (that is, with no currently active faults), essentially single fault tolerant, as determined by the CAA, for electrical, electrically detectable, and electronic failures with respect to LOPC events;	Listed for reference only
5.10.5.3 Not have single failures that result in hazardous EPU effect(s); and	
5.10.5.4 Not have likely failures or malfunctions that lead to local events in the intended aircraft installation, such as arcing, fire, overheat, or other failures that result in a hazardous EPU effect due to an EPU control 's failure or malfunction.	
5.10.6 System Safety Assessment—This assessment must identify faults or failures that affect normal operation together with the predicted frequency of occurrence of these faults or failures.	
5.10.7 Protection Systems:	
5.10.7.1 The design and functioning of EPU control devices and systems, together with EPU instruments and operating and maintenance instructions, must provide reasonable assurance that those EPU operating limitations that affect the structural integrity of the rotating parts, or the electrical integrity of the EPU electrical system will not be exceeded in service.	
5.10.7.2 When electronic overspeed protection systems are provided, the design must include a means for testing, at least once per EPU start/stop cycle, to establish the availability of the protection function. The means must be such that a complete test of the system can be achieved in the minimum number of cycles. If the test is not fully automatic, the requirement for a manual test must be contained in the EPU instructions for operation.	
5.10.7.3 When overspeed protection is provided through hydromechanical or mechanical means, it must be demonstrated by test or other acceptable means that the overspeed function remains available between inspection and maintenance inspection, overhaul, repair, preservation, and the replacement of parts but excludes preventive maintenance. Subcommittee: F39.02 Standard: F2799 periods.	
5.10.8 Aircraft-supplied Data—Single failures leading to loss, interruption or corruption of aircraft-supplied data (other than power command signals from the aircraft), or shared between independent electrodynamic systems within a single EPU or fully independent EPU systems must:	
5.10.8.1 Not result in a hazardous EPU effect for any EPU; and	

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5.10.8.2 Be detected and accommodated. The accommodation strategy must not result in an unacceptable change in power or an unacceptable change in EPU operating characteristics. The effects of these failures on EPU power and on EPU operating characteristics throughout the declared operating envelope and operational environment must be evaluated and documented in the EPU installation instructions.	Listed for reference only
5.10.9 EPU Control System Electrical Power: NOTE 3: The historic basis for this section was to address the use of aircraft supplied electrical power to the engine control system in addition to the use of a dedicated electrical power source, very typically an engine driven permanent magnet alternator (PMA). The aircraft supplied electrical power was most often used as a backup to the PMA electrical power.	
5.10.9.1 The EPU control system must be designed such that the loss, malfunction, or interruption of the EPU control system a combination of components, parts, and elements that are interconnected to perform one or more functions. Subcommittee: F39.03 Standard: F3153 electrical power source will not result in any of the following:	
(1) A hazardous EPU effect, or	
(2) The unacceptable transmission of erroneous data information that supports or describes, or both, the original aircraft design, alteration, or repair including the following: (1) drawings, sketches, and/or photographs; (2) engineering analysis; (3) engineering orders; and (4) operating limitations. Subcommittee: F39.01 Standard: F2639, or	
(3) The continued operation, running of the EPU in the absence of the control function.	
5.10.9.2 The primary electrical power source for the EPU control system must have sufficient capacity to ensure its operation at least as long as the EPU when using all possible EPU electrical power sources.	
5.10.9.3 If any electrical power is supplied from the aircraft to the EPU control system for powering on and operating the EPU, the need for and the characteristics of this electrical power, including transient and steady state voltage limits, must be identified and declared in the EPU instructions for installation.	
5.10.10 EPU Shut Down Means—Means must be provided for shutting down the EPU rapidly.	
5.11 Instrument or Sensor Connection:	
5.11.1 Provisions must be made for the installation of instrumentation or sensors necessary to ensure EPU operation within all operating limitations.	
5.11.2 The instrument or sensor connections must be designed or labeled to ensure a correct connection.	
5.11.3 Any instrumentation on which the Safety Analysis (see 5.19) depends must be specified and declared mandatory in the EPU installation instructions and approval documentation.	
5.11.4 The sensors, together with their data transmission hardware and signal conditioning, must be segregated electrically and physically to the extent necessary, to ensure that the probability of a fault propagating from instrumentation and monitoring functions to control functions, or vice versa, is consistent with the failure effect of the fault.	Listed for reference only

3.5 Subpart C, Design and Construction; Reciprocating Aircraft Engines

In light of magniX special condition no. 1, and in combination with earlier findings presented by HS Advance Concepts personnel, 14 CFR 33 Subpart C will not be addressed in this document.

3.6 Subpart D, Block Tests; Reciprocating Aircraft Engines

In light of magniX special condition no. 1, and in combination with earlier findings presented by HS Advance Concepts personnel, 14 CFR 33 Subpart D will not be addressed in this document.

3.7 Subpart E, Design and Construction; Turbine Aircraft Engines

In light of magniX special condition no. 1, and in combination with earlier findings presented by HS Advance Concepts personnel, 14 CFR 33 Subpart E will not be addressed in this document.

However, a review of the magniX special conditions nos.12 through 18 does indicate alignment with the traditional structure of 14 CFR 33 Subpart E. As a result, those special conditions are addressed in this section.

3.7.1 Unique Aspects of X-57 to This Subpart / magniX Special Conditions

As pointed out earlier, the rotating elements of an electric motor are more like that of a gas turbine and, as such, are subjected to design constraints more commonly associated with pure rotation, as opposed to reciprocating loads. After reviewing the preamble and content of the magniX special conditions, it is apparent AIR-6A1, Engine and Propeller Standards Branch is in agreement.

It is known that Research and Development (R&D) activities are taking place involving EPU-powered turbofan-type engines exceeding 2 MW and that they are being installed on existing airframes certified under 14 CFR part 25[13]. Should these development activities bear fruit, icing strategies will need to be developed and tested. As a result, the prescriptive elements of 14 CFR 33 Subpart E concerning icing, bird, hail and rain ingestion, as well as other robust features required today in turbine-powered commercial service aircraft may need to be folded into future revisions of ASTM F3338.

3.7.2 magniX Special Conditions

magniX Special Conditions	
12. Stress analysis. (a) A mechanical, thermal, and electrical stress analysis must show there is a sufficient design margin to prevent unacceptable operating characteristics. (b) Maximum stresses in the engine must be determined by tests, validated analysis, or a combination thereof, and must be shown not to exceed minimum material properties.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.14. E3338 adds additional specificity concerning electrical stress analysis.]

[13] See, for example, https://www.airbus.com/innovation/future-technology/electric-flight/e-fan-x.html#ove

13. Critical and life-limited parts. (a) The applicant must show by a safety analysis or means acceptable to the Administrator, whether rotating or moving components, bearings, shafts, static parts, and non-redundant mount components should be classified, designed, manufactured, and managed throughout their service life as critical or life-limited parts. (1) Critical part means a part that must meet prescribed integrity specifications to avoid its primary failure, which is likely to result in a hazardous engine effect, as defined in special condition no. 17(d)(2) of these special conditions. (2) Life-limited part means a rotor and major structural static part whose failure can result in a hazardous engine effect due to a low-cycle fatigue (LCF) mechanism or any LCF driven mechanism coupled with creep. A life limit is an operational limitation that specifies the maximum allowable number of flight cycles that a part can endure before the applicant must remove it from the engine. (b) The applicant must establish the integrity of each critical part or life-limited part by providing the following three plans to the Administrator for approval: (1) An engineering plan that establishes and maintains that the combination of loads, material properties, environmental influences, and operating conditions, including the effects of engine parts influencing these parameters, are sufficiently well-known and predictable by validated analysis, test, or service experience. The engineering plan must ensure each critical part or life-limited part is withdrawn from service at an approved life before hazardous engine effects can occur. The engineering plan must establish activities to be executed both pre- and post-certification. magniX must perform appropriate damage tolerance assessments to address the potential for failure from material, manufacturing, and service-induced anomalies within the approved life of the part. The approved life must be published in the mandatory ICA. (2) A manufacturing plan that identifies the specific manufacturing definition (drawings, procedures, specifications, etc.) necessary to consistently produce critical or life-limited parts with the attributes required by the engineering plan. (3) A service management plan that defines in-service processes for maintenance and repair of critical or life-limited parts that maintain attributes consistent with those required by the engineering plan. These processes must become part of the mandatory ICA.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.15. In many ways, this special condition is more prescriptive and richer in detail than the MoC proposed in F3338. One interesting aspect of F3338 is Subsection 5.15.3.4 which allows many compliance aspects in this section to be sidestepped in cases where failed hubs, rotors or blade retention components provided their failures are contained and are assigned a severity level of major or less.]
14. Lubrication system. (a) The lubrication system must be designed and constructed to function properly between scheduled maintenance intervals in all flight attitudes and atmospheric conditions in which the engine is expected to operate. (b) The lubrication system must be designed to prevent contamination of the engine bearings by particle debris. (c) The applicant must demonstrate by test, validated analysis, or a combination thereof, the unique lubrication attributes and functional capability of (a) and (b).	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.16. In many ways, this special condition is more prescriptive and richer in detail than the MoC proposed in F3338.]
15. Power response. The design and construction of the engine must enable an increase— (a) From the minimum power setting to the highest-rated power without detrimental engine effects; and (b) From the minimum obtainable power while in-flight and while on the ground to the highest-rated power within a time interval for safe operation of the aircraft.	*Applies to X-57.* [This type of requirement is usually reserved for Operation Tests. However, the Administrator is appropriately concerned with overstress of components caused by unique and dynamic accel and decel conditions. The treatment of jam accels and decels in ASTM F3338-20 Section 5.21.9 is inadequate. There should be more reliance on the prescriptive elements found in §33.73.]
16. Continued rotation. If the design allows any of the engine main rotating systems to continue to rotate after the engine is shut down while in-flight, this continued rotation must not result in any hazardous engine effects, as specified in special condition no. 17(d)(2).	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.17 for additional explanation and prescriptive MoC requirements.]

17. Safety analysis. (a) The applicant must comply with § 33.75(a)(1), (a)(2), and (a)(3) using the failure definitions in special condition no. 17(d). (b) If the failure of such elements is likely to result in hazardous engine effects, then the applicant may show compliance by reliance on the prescribed integrity requirements of § 33.15, special condition no. 9, or special condition no. 13, as determined by analysis. The failure of such elements and associated prescribed integrity requirements must be stated in the safety analysis. (c) The applicant must comply with 14 CFR 33.75(d) and (e) using the failure definitions in special condition no. 17(d) of this special condition. (d) Unless otherwise approved by the Administrator, the following definitions apply to the engine effects when showing compliance with this condition: (1) An engine failure in which the only consequence is the inability to dispatch the aircraft will be regarded as a minor engine effect. (2) The engine effects in § 33.75(g)(2) are hazardous engine effects with the addition of: Electrocution of crew, passengers, operators, maintainers, or others. (3) Any other engine effect is a major engine effect.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.19, which is essentially equivalent to this special condition.]
18. Ingestion. (a) Ingestion from likely sources (foreign objects, birds, ice, rain, hail) must not result in unacceptable power loss, or in hazardous engine effects as defined by special condition no. 17(d)(2). (b) If the design of the engine relies on features, attachments, or systems that may be supplied by the installer for the prevention of unacceptable power loss or hazardous engine effects following potential ingestion, then the features, attachments, or systems must be documented in the engine installation manual.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.20 for additional explanation and prescriptive MoC requirements. ASTM F3338-20 Section 5.20 specifies additional and EPU-unique failure modes that could result from foreign object ingestion. Further reference to 14 CFR 33.76 and 33.77 and 33.78 may be necessary to fully define an MoC.]
19. Liquid systems. Each liquid system used for lubrication or cooling of engine components must be designed and constructed to function properly in all flight attitudes and atmospheric conditions in which the engine is expected to operate. If a liquid system used for lubrication or cooling of engine components is not self-contained, the interfaces to that system must be defined in the engine installation manual.	*Does not apply to X-57. [To my knowledge, all EPU components are air cooled.]*

3.7.3 Certification Basis

Subpart E—Design and Construction; Turbine Aircraft Engines	**Notes**
§33.73 Power or thrust response.	
The design and construction of the engine must enable an increase-- (a) From minimum to rated takeoff power or thrust with the maximum bleed air and power extraction to be permitted in an aircraft, without overtemperature, surge, stall, or other detrimental factors occurring to the engine whenever the power control lever is moved from the minimum to the maximum position in not more than 1 second, except that the Administrator may allow additional time increments for different regimes of control operation requiring control scheduling; and (b) From the fixed minimum flight idle power lever position when provided, or if not provided, from not more than 15 percent of the rated takeoff power or thrust available to 95 percent rated takeoff power or thrust in not over 5 seconds. The 5-second power or thrust response must occur from a stabilized static condition using only the bleed air and accessories loads necessary to run the engine. This takeoff rating is specified by the applicant and need not include thrust augmentation.]	Retained as reference for magniX special condition 15.
§33.74 Continued Rotation	
	Retained as reference for magniX special condition 16.
§33.75 Safety analysis.	

Subpart E—Design and Construction; Turbine Aircraft Engines	**Notes**
(a) (1) The applicant must analyze the engine, including the control system, to assess the likely consequences of all failures that can reasonably be expected to occur. This analysis will take into account, if applicable:	Retained as reference for magniX special condition 17.
(i) Aircraft-level devices and procedures assumed to be associated with a typical installation. Such assumptions must be stated in the analysis.	
(ii) Consequential secondary failures and latent failures.	
(iii) Multiple failures referred to in paragraph (d) of this section or that result in the hazardous engine effects defined in paragraph (g)(2) of this section.	
(2) The applicant must summarize those failures that could result in major engine effects or hazardous engine effects, as defined in paragraph (g) of this section and estimate the probability of occurrence of those effects. Any engine part, the failure of which could reasonably result in a hazardous engine effect, must be clearly identified in this summary.	
(3) The applicant must show that hazardous engine effects are predicted to occur at a rate not in excess of that defined as extremely remote (probability range of 10^{-7} to 10^{-9} per engine flight hour). Since the estimated probability for individual failures may be insufficiently precise to enable the applicant to assess the total rate for hazardous engine effects, compliance may be shown by demonstrating that the probability of a hazardous engine effect arising from an individual failure can be predicted to be not greater than 10^{-8} per engine flight hour. In dealing with probabilities of this low order of magnitude, absolute proof is not possible, and compliance may be shown by reliance on engineering judgment and previous experience combined with sound design and test philosophies.	
(4) The applicant must show that major engine effects are predicted to occur at a rate not in excess of that defined as remote (probability range of 10^{-5} to 10^{-7} per engine flight hour).	
(b) The FAA may require that any assumption as to the effects of failures and likely combination of failures be verified by test.	
(c) The primary failure of certain single elements cannot be sensibly estimated in numerical terms. If the failure of such elements is likely to result in hazardous engine effects, then compliance may be shown by reliance on the prescribed integrity requirements of §§33.15, 33.27, and 33.70 as applicable. These instances must be stated in the safety analysis.	
(d) If reliance is placed on a safety system to prevent a failure from progressing to hazardous engine effects, the possibility of a safety system failure in combination with a basic engine failure must be included in the analysis. Such a safety system may include safety devices, instrumentation, early warning devices, maintenance checks, and other similar equipment or procedures. If items of a safety system are outside the control of the engine manufacturer, the assumptions of the safety analysis with respect to the reliability of these parts must be clearly stated in the analysis and identified in the installation instructions under §33.5 of this part.	Retained as reference for magniX special condition 17.
(e) If the safety analysis depends on one or more of the following items, those items must be identified in the analysis and appropriately substantiated.	
(1) Maintenance actions being carried out at stated intervals. This includes the verification of the serviceability of items that could fail in a latent manner. When necessary to prevent hazardous engine effects, these maintenance actions and intervals must be published in the instructions for continued airworthiness required under §33.4 of this part. Additionally, if errors in maintenance of the engine, including the control system, could lead to hazardous engine effects, the appropriate procedures must be included in the relevant engine manuals.	
(2) Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details of this satisfactory functioning must be published in the appropriate manual.	
(3) The provisions of specific instrumentation not otherwise required.	
(4) Flight crew actions to be specified in the operating instructions established under §33.5.	
(f) If applicable, the safety analysis must also include, but not be limited to, investigation of the following:	
(1) Indicating equipment;	
(2) Manual and automatic controls;	
(3) Compressor bleed systems;	
(4) Refrigerant injection systems;	
(5) Gas temperature control systems;	
(6) EPU speed, power, or thrust governors and motor converter control systems;	
(7) EPU overspeed or overtemperature~~, or topping limiters~~;	
(8) Propeller control systems; and	

Subpart E—Design and Construction; Turbine Aircraft Engines	Notes
(9) Engine or propeller thrust reversal systems.	
(g) Unless otherwise approved by the FAA and stated in the safety analysis, for compliance with part 33, the following failure definitions apply to the engine:	
(1) An EPU failure in which the only consequence is partial or complete loss of thrust or power (and associated EPU services) from the EPU will be regarded as a minor engine effect.	
(2) The following effects will be regarded as hazardous engine effects:	See magniX special condition 17 for additional hazardous effects.
(i) Non-containment of high-energy debris;	
(ii) Concentration of toxic products in the engine bleed air intended for the cabin sufficient to incapacitate crew or passengers;	
(iii) Significant thrust in the opposite direction to that commanded by the pilot;	
(iv) Uncontrolled fire;	
(v) Failure of the engine mount system leading to inadvertent engine separation;	
(vi) Release of the propeller by the engine, if applicable; and	
(vii) Complete inability to shut the engine down.	
(3) An effect whose severity falls between those effects covered in paragraphs (g)(1) and (g)(2) of this section will be regarded as a major EPU effect. [ref: Amendment. 33-24, 72 FR 50867, Sept. 4, 2007]	

3.8 Subpart F, Block Tests; Turbine Aircraft Engines

In light of magniX special condition 1, and in combination with earlier findings presented by HS Advance Concepts personnel, 14 CFR 33 Subpart E will not be addressed in this document.

However, a review of the magniX special conditions 19 through 31 does indicate alignment with the traditional structure of 14 CFR 33 Subpart F. As a result, those special conditions are addressed in this section.

3.8.1 Unique Aspects of X-57 to This Subpart / magniX Special Conditions

When considering the application of 14 CFR 33 to Block Tests, there is a critical need to develop endurance test methods for EPUs. The normal tendency is to migrate to the 14 CFR Part 33 Endurance test, a hallmark or benchmark for aviation engines. However, the 14 CFR Part 33 Endurance test methods as codified may not be the most applicable or meaningful approach for conducting durability testing of an EPU. However, in the absence of other options, 14 CFR 33.49 and 33.87 are a good starting point, but with the view of tailoring their suitability to EPU considerations.

The fundamental requirement of an FAA Endurance test is to establish airworthiness; the industry has 50+ years' experience that 14 CFR 33.49 and 33.87, viewed as accelerated tests, have proven to be quite effective for aircraft engines. Our position, while here in the earliest stages of a transition to new technology, is that it is necessary and appropriate to maintain connectivity to tests that have stood the test of time. Many arguments can be made that dispute the direct application of combustion engine test standards to electric propulsion. However, there is a future time and place to substantiate and make those changes.

Further, given that this technology is in a discovery phase, speculation quickly leads to the conclusion that VTOL applications may rely heavily on One Engine Inoperative (OEI) EPU ratings. 14 CFR 33.87 contains testing specifically tailored to evaluate and certify OEI ratings.

The acronym "OEI" refers to the particular ability of a multi-engine turbine-powered rotorcraft to place a momentary requirement for excess power on the remaining turbine to ensure the survival of the rotorcraft and its occupants. However, the term "OEI" is also used in transport category airplanes, as well as both normal and transport category rotorcraft, to refer to climb performance, not the need for excess power to a remaining turbine engine on a multi-engine rotorcraft. In normal category airplanes, 14 CFR 23, where the EPU applicants will likely be found, the climb performance term is "critical loss of thrust," and that term can be found in 14 CFR 23.2115(c), Takeoff performance; 23.2120(b) Climb requirements; 23.2125(a)(2)&(3) Climb information; 23.2135(c) Controllability; 23.2140(c) Trim; and 23.2150(c) Stall characteristics, stall warning, and spins. 14 CFR 25 also uses the term "one-engine-inoperative" in 25.107, 25.121, and 25.123. It can also be found in rotorcraft climb performance in both normal category rotorcraft, 14 CFR 27.67, and in transport category rotorcraft, in 14 CFR 29.67.

Therefore, while this EPU technology is in its discovery phase, the authors felt that it would be counterproductive to change the "OEI" term for vertical lift-capable applications of EPU and to ensure that a place is open for the potential applicants to enter into discussions with the aircraft certification office. However, in both ASTM F3338-20 and the magniX special conditions, the authors opted to refer to this with the new term "rated temporary power". To avoid widespread and counterproductive changes to the portions of the CFR, the terms "rated temporary power" and "OEI" may be used interchangeably throughout this section.

In the face of continuous technological advancements in the field, it is virtually impossible to anticipate every single EPU topology. As a result, the approach taken in this report to assess durability testing of an EPU is, to begin with, the basics, leaving a determination of the most practical and meaningful technical approach to validate durability for airworthiness.

Unique Aspects of Electric Motor Propulsion

It is not enough to provide an edit of 14 CFR 33.87 alone as there are other CFRs which provide additional input to determining the successful completion of the Endurance test. In reviewing IEC 60349-4, there are several "Type Tests" intended to prove the ratings, characteristics and performance of new types of *'Machines'*. Table 4 of this IEC lists the *'Type Tests'* to be performed. In reviewing this list, it is apparent they can be distributed to appropriate sections of 14 CFR 33. Table 4 lists the tests recommended within the IEC, the applicable IEC Clause, and a recommendation of the CFR Section wherein they should be incorporated.

Table 4. Recommended Tests in IEC and 14 CFR 33

Test Category	IEC 60349-4 Clause	14 CFR 33 Section
Temperature rise with converter	8.1	33.85
Characteristics	8.2	33.85
No-load test	9.2.2	33.85
Current load test	9.2.3	33.85

Test Category	IEC 60349-4 Clause	14 CFR 33 Section
Overspeed	8.3	33.27 *(Test to be conducted with the motor only in the case of a certified propeller application. In the case of an integral ducted fan design, the test is to be run on the entire EPU assembly.)*
Dielectric	9.4	33.93
Vibration	8.4	33.83
Open terminal temperature test	10.2	33.85
[Acoustic] Noise (optional)	8.5	-

One fundamental assumption made herein is to consider the electric motor and the motor driver as an inseparable pairing. It is generally recognized in the industry that the controller-converter-PMM interfaces are complex and highly technical which can have significant influences over the durability-related aspects of both the converter and the motor. A short list of potential issues arising from a poorly executed interface include vibration, poor efficiency, voltage transients, power transistor failures, aircraft ground isolation failures, loss of thrust, loss of motor control, overheating and undesirable electrical and acoustic emissions. To reinforce this point, IEC 60349-4, Electric traction – Rotating electrical machines for rail and road vehicles – Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter, Clause 7.2.2 states the following: “Unless otherwise agreed, the type test may be repeated if the electrical output characteristics of the converter are changed.”

In assembling this report, the following unique aspects of brushless DC-based EPUs were a special consideration based on the authors’ historic experience:

- Performance of automatic current sensing and limiting devices
- Thermal stress within solid-state switching devices and the PMM stator
- Interactions with motor back-EMF characteristics
- Rotor magnet degaussing due to thermal affects or gross controller timing errors
- Integrity of data from rotor position feedback systems
- Regenerative modes of operation

Motor drivers typically contain a phase current limit device which will limit the motor current automatically to reduce solid state switching device thermal stress and promote longevity. In most DC electric motor operating modes, average phase current is nearly linearly proportional to motor torque. Steady-state torque is a function of the fundamental propulsor torque requirements, motor rotor windage losses and bearing losses. Transient torque is a function of the steady-state torque plus the rotating mass moment of inertia and its acceleration rate.

Motors typically self-regulate the current which can be applied to them through interactions with back-EMF. Back-EMF is a voltage level that a motor naturally self-generates within its stator as the rotor turns. The faster the rotor turns, the higher the back-EMF magnitude and frequency. A converter drives current into the motor by applying voltage waveform to its terminals which exceeds the back-EMF generated by the motor itself. The higher the differential voltage, the higher the current (torque).

In the most general terms, if the motor receives a step command to full thrust, the converter attempts to apply full electrical power to the motor stator. If the motor is turning slowly, with low levels of back-EMF, the converter current could exceed the limiting current specified by the motor or converter designer. To counter this, most motor converters incorporates one or more internal shunts or other current sensing technologies to monitor output current. If the controller senses high converter current, it will automatically reduce the average motor terminal voltage, usually through a pulse width modulation technique, to hold the converter right at current limit and the motor will accelerate at its maximum rate. As the motor continues to accelerate (and the back-EMF increases), the current drops. The controller responds by applying more converter average terminal voltage until the current limit is again reached. The effect is that the motor accelerates at the maximum possible rate as dictated by the current limiting circuitry. The final operating RPM of the EPU is dictated by satisfying the airframe RPM request or by going into load equilibrium at the converter current limit.

For example, in one specific topology of motor converter operation at current limit can be the principle thermal stressor on the power switching devices as well as the motor windings. For an EPU with large design margins in both the converter and motor, one could frequently command step changes while relying on the internal current limiting circuitry to prevent EPU thermal damage. On the other hand, a less robust EPU could accumulate thermal damage to the motor and converter. That said, one is again cautioned it is virtually impossible to anticipate every single EPU topology. The safety analysis results of each EPU should be examined to determine critical design features. Emphasis is also placed on the need to measure the open circuit back-EMF during calibration under 14 CFR 33.85 both before and after the endurance test. This is necessary because permanent magnet rotor assemblies which are heated above their Curie temperature will lose their residual magnetism and, thus, their ability to generate the same levels of back-EMF. If allowed to occur this situation can lead to rapid PMM performance degradation through the series of events depicted in Figure 9. Figure 10 illustrates this degradation process and contains a table listing typical Curie temperatures for popular magnetic materials.

Figure 9. Example of Progressive Failure Mode in a Permanent Magnet Motor Thermal Degradation

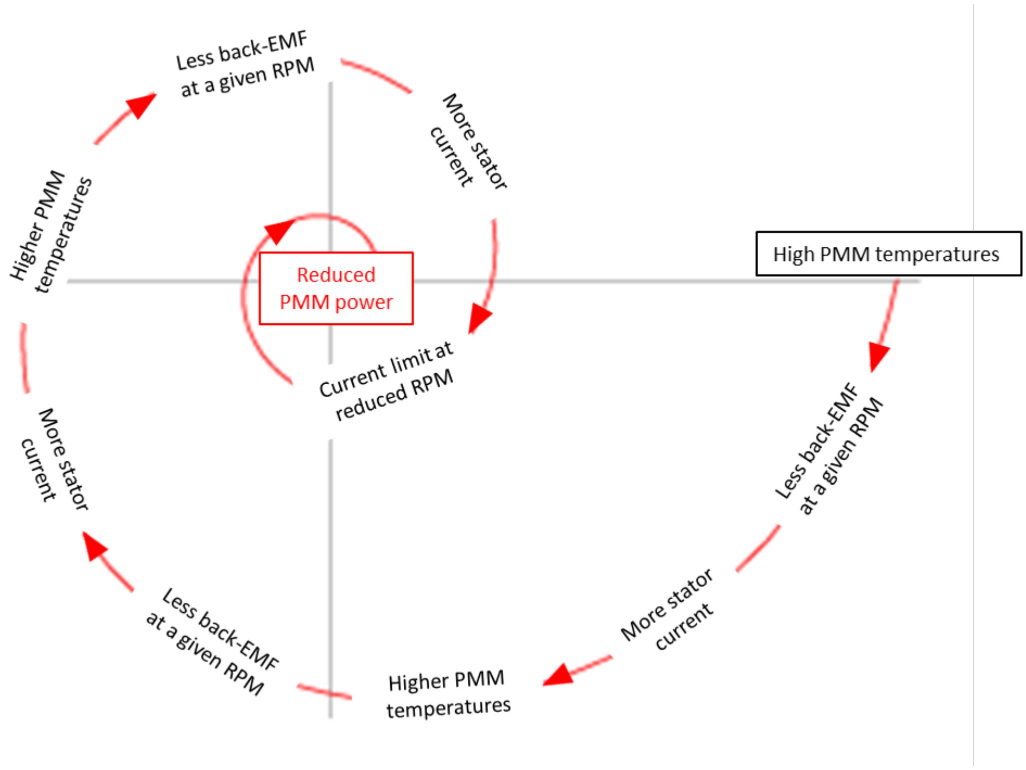
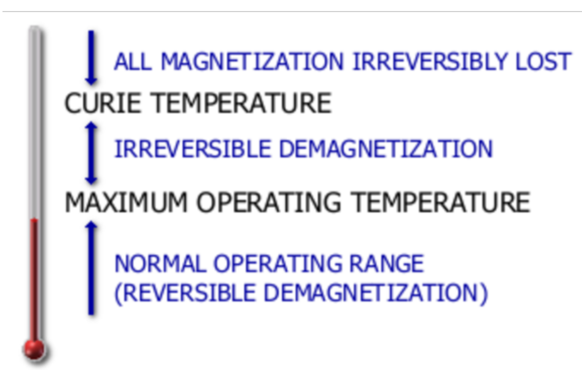


Figure 10. Permanent Magnet Motor Irreversible Thermal Degradation Conditions



Magnet type	Max. Working Temperature (deg. C)	Curie Temperature (deg. C)
NdFeB-s		
N	80	310
M	100	340
H	120	340
SH	150	340
UH	180	350
EH	200	350
AH	230	350
SmCo-s		
SmCo5	250	750
Sm2Co17	250-350	800
AlNiCo		
Sintered	450	760-890
Cast	450-550	810-890
Ferrite-s	250	450

Pre- and post-endurance test validation of the PMM power and the open circuit back-EMF will detect if the PMM is thermally stable.

Automated controllers will typically limit the rate of acceleration so as to avoid ongoing and-or frequent operation in current limit. However, one could envision an airframe back-up system that could bypass a flight control system and give the pilot direct authority to command EPU power. In a back-up situation, the EPU design should anticipate 'jam accels' which would involve accelerations in which the EPU accelerates while in current limit control.

Accurate rotor position feedback is another critical area for the maintenance of optimum motor performance. While many systems employ position feedback systems based on back-EMF techniques or embedded timing coils, these systems can pose problems for reliable controller operation as a result of magnetic "noise" or "current cross-talk" in the stator environment. In some cases, manufacturers have countered problems related to the magnetic environment by relying on timing discs or shaft position encoders, coupled with optical or hall effect devices, for position feedback. These types of systems may require mechanical timing adjustments to ensure optimum motor efficiency. In the event this type of system is used, aspects of the CFR will require that the repeatability of this adjustment is maintained over the course of the endurance test.

While engine decelerations are an aspect of current endurance test profiles, powered regeneration cycles are not. Just as aircraft climb out conditions can result in critical combinations of high system thermal load with marginal cooling conditions, so could a period of high regeneration during aircraft descent. Future consideration should be given to expanding 14 CFR 33.85, Calibration tests, and 14 CFR 33.87 Endurance tests to include test measurements and cycles as appropriate for applications involving regeneration cycles.

As was the case in 14 CFR 33 Subpart B, it is known that R&D activities are taking place involving EPU-powered turbofan-type engines exceeding 2 Megawatt (MW) and that they are being installed on existing airframes certified under 14 CFR 25[14]. Should these development activities bear fruit, the prescriptive elements concerning block testing required today in turbine-powered commercial service aircraft has been left relatively untouched in the following regulatory requirements.

As pointed out earlier, the rotating elements of an electric motor are more similar to that of a gas turbine and, as such, are subjected to design constraints more commonly associated with pure rotation, as opposed to reciprocating loads. After reviewing the preamble and content of the magniX special conditions, it is apparent AIR-6A1, Engine and Propeller Standards Branch is in agreement.

3.8.2 magniX Special Conditions

magniX Special Conditions	
20. Vibration demonstration. (a) The engine must be designed and constructed to function throughout its normal operating range of rotor speeds and engine output power, including defined exceedances, without inducing excessive stress in any of the engine parts because of vibration and without imparting excessive vibration forces to the aircraft structure. (b) Each proposed engine design must undergo a vibration survey to establish that the vibration characteristics of those components that may be subject to induced vibration are acceptable throughout the declared flight envelope and engine operating range for the specific installation configuration. The possible sources of the induced vibration that the survey must assess are mechanical, aerodynamic, acoustical, or electromagnetic. This survey must be shown by test, validated analysis, or a combination thereof.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.21.4 for additional explanation and prescriptive MoC requirements.]
21. Overtorque. When approval is sought for a transient maximum engine overtorque, the applicant must demonstrate by tests, validated analysis, or a combination thereof, that the engine is capable of continued operation after operating at the maximum engine overtorque condition without maintenance action.	*May or may not apply to X-57.* [Reference ASTM F3338-20 Section 5.21.5 for additional explanation and prescriptive MoC requirements.]

[14] See, for example, https://www.airbus.com/innovation/future-technology/electric-flight/e-fan-x.html#ove

magniX Special Conditions	
22. Calibration assurance. Each engine must be subjected to calibration tests to establish its power characteristics and the conditions both before and after the endurance and durability demonstrations specified in special conditions nos. 23 and 26.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.21.7. In addition, the authors recommend the addition of the following IEC Tests to the MoC: (1) EPU Cooling requirements per IEC 60349-4 Clause 8.1 (2) EPU Performance characteristics per IEC 60349-4 Clause 8.2 (3) EPU no load characterization test per IEC 60349-4 Clause 9.2.2 (4) EPU Current-load characterization test per IEC 60349-4 Clause 9.2.3 (5) EPU Open terminal temperature rise test per IEC 60349-4 Clause 10.2]
23. Endurance demonstration. The applicant must subject the engine to an endurance demonstration acceptable to the Administrator to demonstrate the limit capabilities of the engine. The endurance demonstration elevates and decreases the engine's power settings, and dwells at the power settings for durations that produce the extreme physical conditions the engine experiences at rated performance levels, operational limits, and at any other conditions or power settings that are required to verify the limit capabilities of the engine.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.21.3. However, for the reasons laid out in Section 3.6.1 of this document, the author encourages the continued use of the prescriptive guidance found in 14 CFR 33.87.]
24. Temperature limit. The engine design must demonstrate its capability to endure operation at its temperature limits plus an acceptable margin. The applicant must quantify and justify the margin at each rated condition to the Administrator. The demonstration must be repeated for all declared duty cycles and associated ratings.	*May apply to X-57.* [Reference a mark-up of 14 CFR 33.88 in Section 3.6.2 of this document as a potential MoC.]
25. Operation demonstration. The engine design must demonstrate safe operating characteristics, including but not limited to, power cycling, acceleration, and overspeeding, throughout its declared flight envelope and operating range. The declared engine operational characteristics must account for installation loads and effects.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.21.8 for additional explanation and prescriptive MoC requirements. Note the special condition requires and accounting for the "effects of installation loads and effects"]
26. Durability demonstration. The engine must be subjected to a durability demonstration to show that each part of the engine has been designed and constructed to minimize the development of any unsafe condition of the system between overhaul periods, or between engine replacement intervals if overhaul is not defined. This test must simulate the conditions in which the engine is expected to operate in-service, including typical start-stop cycles.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.21.3. The ASTM Specification fails to provide a prescriptive durability MoC at this time.]
27. System and component tests. The applicant must show that systems and components will perform their intended functions in all declared environmental and operating conditions.	*May apply to X-57.* [This generally applies to special tests which are required, but not normally well integrated the block test plans due to special circumstances. One example generally encountered is cold starting demonstrations.]

magniX Special Conditions	
28. Rotor locking demonstration. If shaft rotation is prevented by a means to lock the rotor(s), the engine must demonstrate reliable rotor locking performance and that no hazardous effects will occur.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.22 for additional explanation and prescriptive MoC requirements.]
29. Teardown inspection. The applicant must comply with either (a) or (b) as follows: (a) Teardown evaluation. (1) After the endurance and durability demonstrations have been completed, the engine must be completely disassembled. Each engine component must be within service limits and eligible for continued operation in accordance with the information submitted for showing compliance with § 33.4, Instructions for Continued Airworthiness. (2) Each engine component having an adjustment setting and a functioning characteristic that can be established independent of installation on or in the engine must retain each setting and functioning characteristic within the limits that were established and recorded at the beginning of the endurance and durability demonstrations. (b) Non-Teardown evaluation. If a teardown is not performed for all engine components, then the life limits for these components must be established based on the endurance and durability demonstrations.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.23, which is essentially equivalent to this special condition.]
30. Containment. The engine must provide containment features that protect against likely hazards from rotating components as follows— (a) The design of the case surrounding rotating components must provide for the containment of the rotating components in the event of failure unless the applicant shows that the rotor has a margin to burst that would justify no need for containment features. (b) If the margin to burst shows the case must have containment features in the event of failure, the case must provide for the containment of the failed rotating components. The applicant must define by test, validated analysis, or combination thereof, and document in the installation manual the energy level, trajectory, and size of any fragments released from damage caused by the main rotor failure that pass forward or aft of the surrounding case.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.24. In many ways, this special condition is more prescriptive and richer in detail than the MoC proposed in F3338.]
31. Operation with a variable pitch propeller or fan. The applicant must conduct functional demonstrations including feathering, negative torque, negative thrust, and reverse thrust operations, as applicable, with a representative propeller. These demonstrations may be conducted as part of the endurance and durability demonstrations.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.25 for additional explanation and prescriptive MoC requirements.]
32. General conduct of tests. (a) Maintenance of the engine may be made during the tests in accordance with the service and maintenance instructions contained in the proposed ICA. (b) The applicant must subject the engine or its parts to maintenance and additional tests that the Administrator finds necessary if– (1) The Frequency of the service is excessive; (2) The number of stops due to engine malfunction is excessive; (3) Major repairs are needed; or (4) Replacement of a part is found necessary during the tests or as the result of findings from the teardown inspection. (c) Upon completion of all demonstrations and testing specified in these special conditions, the engine and its components must be – (1) Within serviceable limits; (2) Safe for continued operation; and (3) Capable of operating at declared ratings while remaining within limits.	*Applies to X-57.* [Reference ASTM F3338-20 Section 5.23, which is essentially equivalent to this special condition.]

3.8.3 Certification Basis

The following excerpts from 14 CFR 33 are requirements which remain active when taking magniX special condition 1 into account or were referenced in the preceding Section of this document. In some circumstances, the Regulation has been updated in red text to reflect possible wording for an MoC.

Subpart F—Block Tests; Turbine Aircraft Engines	**Notes**
§33.81 Applicability.	
This subpart prescribes the block tests and inspections for engines. [ref: Doc. No. 3025, 29 FR 7453, June 10, 1964, as amended by Amendment 33-6, 39 FR 35468, Oct. 1, 1974]	*Applies to X-57*
§33.82 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. [ref: Amendment 36-6, 39 FR 35468, Oct. 1, 1974]	*Applies to X-57*
§33.87 Endurance test.	
(a) *General.* Each EPU must be subjected to an endurance test that includes a total of at least 150 hours of operation and, depending upon the *concept of operation*[15], consists of one of the series of runs specified in paragraphs (b) through (f) of this section, as applicable. For EPUs tested under paragraphs (b), (c), (d) or (e) of this section, the prescribed 6-hour test sequence must be conducted 25 times to complete the required 150 hours of operation. EPUs for which the 30-second OEI and 2-minute OEI ratings are desired must be further tested under paragraph (f) of this section. The following test requirements apply:	*Modified*
(1) The runs must be made in the order found appropriate by the Administrator for the particular EPU being tested.	*Modified*
(2) Any automatic EPU control that is part of the EPU must control the EPU during the endurance test except for operations where automatic control is normally overridden by manual control or where manual control is otherwise specified for a particular test run.	*Modified*
(3) Power or thrust, motor stator and rotor temperatures, the motor controller/converter heat sink temperature, rotor shaft rotational speed, and, if limited, temperature of external surfaces of the EPU must be at least 100 percent of the value associated with the particular EPU operation being tested. More than one test may be run if all parameters cannot be held at the 100 percent level simultaneously.	*Modified* [In a gas turbine engine, most thermal stressors are directly proportional to the engine gas temperature. However, in an EPU, there are several individual components that should be monitored separately. Separate monitoring is recommended because the cooling means for each may be technically different, or even dependent on completely separate cooling system architectures. IEC 60349-4, Section 8.1.5 contains an example of limits as applied to a PMM.]
(4) An EPU 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 EPU is designed to resist at each applicable operating condition specified in this section.	*New.* [Adopted from 14 CFR 33.49(a).]

[15] *"Concept of Operations" is an approach that the FAA notes has potential for engineering certification framed by the intended operation, as much as it is based on raw adherence to a standard. It is intended to model itself on the Mission Task Element (MTE) method used in recent Unmanned Aircraft System (UAS) tests (see, for example, Belcastro, Klyde, Logan, Newman, Foster, "Experimental Flight Testing for Assessing the Safety of Unmanned Aircraft System Safety-Critical Operations," AIAA AVIATION Forum, 5-9 June 2017, Denver, CO, 17th AIAA Aviation Technology, Integration, and Operations Conference.)*

Subpart F—Block Tests; Turbine Aircraft Engines	Notes
(4) The runs must be made using the lowest limiting supply voltage, and with lubricants and cooling fluids which conform to the specifications specified in complying with §33.7(c).	*Modified* [The motor controller/converter performance is dependent on the EPU supply voltages (reference Annex D of IEC 60349-4). Annex D requires that a nominal, lowest and highest value should be defined. This is an analog to fuel specification, such as ASTM D910 or D1655, which include the net heat of combustion. Net heat of combustion can be thought of as an analog of voltage and fuel flow can be thought of as an analog for current. The lower the net heat of combustion (voltage), the more fuel flow (current) is required to make power. In the case of an EPU, more current typically infers more heating losses (I^2R) which can be a stressor to the motor converter. Therefore, it is appropriate to conduct an EPU endurance test with the lowest possible source voltage. For a battery-powered system, the lowest voltage will occur at the battery's end of discharge state. While grease-packed ball bearings will likely predominate in EPU systems, it is conceivable an EPU with high bearing loadings will require an external lubrication/cooling system. Therefore, it is appropriate to continue to include lubricants in this section. Cooling systems could be either air or liquid-coolant based. As a result, coolants have been added here.]
(5) Maximum air bleed for engine and aircraft services must be used during at least one-fifth of the runs, except for the test required under paragraph (f) of this section, provided the validity of the test is not compromised. However, for these runs, the power or thrust or the rotor shaft rotational speed may be less than 100 percent of the value associated with the particular operation being tested if the FAA finds that the validity of the endurance test is not compromised.	*Not applicable to EPU* [It is highly unlikely bleed air will ever be generated by the EPU itself. Therefore, recommend this section be deleted.]

Subpart F—Block Tests; Turbine Aircraft Engines	**Notes**
(6) Each accessory drive and mounting attachment must be loaded in accordance with paragraphs (a)(6)(i) and (ii) of this section, except as permitted by paragraph (a)(6)(iii) of this section for the test required under paragraph (f) of this section.	*Unchanged* [The section should remain unchanged in anticipation of an accessory drive pad on the EPU. For example, it is conceivable it could be cost effective to incorporate a conventional hydraulic pitch control capability for a propeller.]
(i) The load imposed by each accessory used only for aircraft service must be the limit load specified by the applicant for the EPU drive and attachment point during rated maximum continuous power or thrust and higher output.	*Modified* [No changes due to reasons cited above.]
(ii) The endurance test of any accessory drive and mounting attachment under load may be accomplished on a separate rig if the validity of the test is confirmed by an approved analysis.	*Unchanged* [No changes due to reasons cited above.]
((iii) The applicant is not required to load the accessory drives and mounting attachments when running the tests under paragraphs (f)(1) through (f)(8) of this section if the applicant can substantiate that there is no significant effect on the durability of any accessory drive or EPU component. However, the applicant must add the equivalent EPU output power extraction ~~from the power turbine rotor assembly~~ to the EPU shaft output.	*Modified* [No changes due to reasons cited above.]
(7) During the runs at any rated power or thrust the lubricant inlet temperature and cooling fluid inlet temperature must be maintained at the limiting temperature except where the test periods are not longer than 5 minutes and do not allow stabilization. Likewise, the supply voltage must also be maintained at the limiting low value except where the test periods are not longer than 5 minutes and do not allow stabilization. At least one run must be made with the lubricating and coolant fluid at the minimum pressure limit and at least one run must be made with the lubricating and coolant fluid at the maximum pressure limit with fluid temperature reduced as necessary to allow maximum pressure to be attained. At least one run must be made with the supply voltage at the maximum limit.	*Modified* [Logic is intended to parallel reasons cited above.]
(8) If the number of occurrences of either transient rotor shaft overspeed, EPU overtemperature or transient EPU overtorque is limited, that number of the accelerations required by paragraphs (b) through (g) of this section must be made at the limiting overspeed, overtemperature or overtorque. If the number of occurrences is not limited, half the required accelerations must be made at the limiting overspeed, overtemperature or overtorque.	*Modified* [Logic is intended to parallel reasons cited above. It is conceivable the operating limitations of an EPU could be expanded to both allow, and subsequently limit, transient operations.]
(9) For each engine type certificated for use on supersonic aircraft the following additional test requirements apply:	*Removed* [The application of an EPU to a supersonic-capable aircraft is unlikely at this time.]
(i) To change the thrust setting, the power control lever must be moved from the initial position to the final position in not more than one second except for movements into the fuel burning thrust augmentor augmentation position if additional time to confirm ignition is necessary.	*Not Applicable to EPMS*
(ii) During the runs at any rated augmented thrust the hydraulic fluid temperature must be maintained at the limiting temperature except where the test periods are not long enough to allow stabilization.	*Not Applicable to EPMS*
(iii) During the simulated supersonic runs the fuel temperature and induction air temperature may not be less than the limiting temperature.	*Not Applicable to EPMS*
(iv) The endurance test must be conducted with the fuel burning thrust augmentor installed, with the primary and secondary exhaust nozzles installed, and with the variable area exhaust nozzles operated during each run according to the methods specified in complying with §33.5(b).	*Not Applicable to EPMS*
(v) During the runs at thrust settings for maximum continuous thrust and percentages thereof, the engine must be operated with the inlet air distortion at the limit for those thrust settings.	*Not Applicable to EPMS*
(b) *EPUs other than those used in certain rotorcraft and VTOL applications.* For each EPU, except a rotorcraft or VTOL EPU for which a rating is desired under paragraph (c), (d), or (e) of this section, the applicant must conduct the following runs:	*Modified* [Logic is intended to parallel reasons cited above.]

Subpart F—Block Tests; Turbine Aircraft Engines	**Notes**
(1) *Takeoff and idling.* One hour of alternate five-minute periods at rated takeoff power and thrust and at ~~idling~~ 10% power ~~and thrust~~. The developed powers and thrusts at takeoff and 10% power conditions and their corresponding rotor speed ~~and gas temperature~~ conditions must be as established by the power control in accordance with the schedule established by the manufacturer. The applicant may, during any one period, manually control the rotor speed, power, and thrust while taking data to check performance. ~~For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at takeoff must be at the augmented rating. For engines with augmented takeoff power ratings that do not materially increase operating severity, the amount of running conducted at the augmented rating is determined by the Administrator.~~ In changing the power setting after each period, the power-control lever must be moved in the manner prescribed in paragraph (b)(5) of this section.	
(2) Rated maximum continuous and takeoff power or thrust. Thirty minutes at—	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(i) Rated maximum continuous power or thrust during fifteen of the twenty-five 6-hour endurance test cycles; and	*Unchanged*
(ii) Rated takeoff power or thrust during ten of the twenty-five 6-hour endurance test cycles.	*Unchanged*
(3) Rated maximum continuous power or thrust. One hour and 30 minutes at rated maximum continuous power or thrust.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(4) *Incremental cruise power and thrust.* Two hours and 30 minutes at the successive power lever positions corresponding to at least 15 approximately equal speed and time increments between maximum continuous EPU rotational speed ~~and ground or minimum idle~~ 46% rotational speed. For EPUs operating at constant speed, the thrust and power may be varied in place of speed. If there is significant peak vibration anywhere between ground idle and maximum continuous conditions, the number of increments chosen may be changed to increase the amount of running made while subject to the peak vibrations up to not more than 50 percent of the total time spent in incremental running.	*Modified* [It is logical to continue to expose the EPU to this test. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(5) *Acceleration and deceleration runs.* 30 minutes of accelerations and decelerations, consisting of six cycles from ~~idling~~ 10% power and thrust to rated takeoff power and thrust and maintained at the takeoff power lever position for 30 seconds and at the ~~idling~~ 10% power lever position for approximately four and one-half minutes. In complying with this paragraph, the power-control lever must be moved from one extreme position to the other in not more than one second, except that, if different regimes of control operations are incorporated necessitating scheduling of the power-control lever motion in going from one extreme position to the other, a longer period of time is acceptable, but not more than two seconds.	*Unchanged* [Logic is intended to parallel reasons cited above. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(6) *Starts.* One hundred starts must be made~~., of which 25 starts must be preceded by at least a two-hour engine shutdown. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time, before attempting a normal start. There must be at least 10 normal restarts with not longer than 15 minutes since engine shutdown. The remaining starts may be made~~ approximately 50 of these starts must be performed after completing the 150 hours of endurance testing.	*Modified* [As is the case for a gas turbine, starting is a critical phase for a PMM in that special circuits and/or logic is used to detect the rotor location and to begin the acceleration process. However, an EPU is much less likely to be affected by heat soaks. Therefore, requirements unique to a gas turbine engine have been deleted.]
(c) *Rotorcraft or VTOL EPUs for which a 30-minute OEI power rating is desired.* For each rotorcraft or VTOL EPU for which a 30-minute OEI power rating is desired, the applicant must conduct the following series of tests:	*Modified* [It is very logical VTOLs will seek a 30-minute OEI power rating.]

Subpart F—Block Tests; Turbine Aircraft Engines	**Notes**
(1) *Takeoff and idling.* One hour of alternate 5-minute periods at rated takeoff power and at ~~idling~~ 10% power. The developed powers at takeoff and ~~idling~~ 10% power conditions and their corresponding rotor speed ~~and gas temperature~~ conditions must be as established by the power control in accordance with the schedule established by the manufacturer. During any one period, the rotor speed and power may be controlled manually while taking data to check performance. ~~For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at rated takeoff power must be at the augmented power rating.~~ In changing the power setting after each period, the power control lever must be moved in the manner prescribed in paragraph (c)(5) of this section.	*Modified* [Logic is intended to parallel reasons cited above. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(2) *Rated maximum continuous and takeoff power.* Thirty minutes at—	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(i) Rated maximum continuous power during fifteen of the twenty-five 6-hour endurance test cycles; and	*Unchanged*
(ii) Rated takeoff power during ten of the twenty-five 6-hour endurance test cycles.	*Unchanged*
(3) Rated maximum continuous power. One hour at rated maximum continuous power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(4) Rated 30-minute OEI power. Thirty minutes at rated 30-minute OEI power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(5) *Incremental cruise power.* Two hours and 30 minutes at the successive power lever positions corresponding with not less than 15 approximately equal speed and time increments between maximum continuous EPU rotational speed and ~~ground or minimum idle~~ 46% rotational speed. For EPUs operating at constant speed, power may be varied in place of speed. If there are significant peak vibrations anywhere between ~~ground idle~~ 46% rotational speed and maximum continuous conditions, the number of increments chosen must be changed to increase the amount of running conducted while subject to peak vibrations up to not more than 50 percent of the total time spent in incremental running.	*Modified* [It is logical to continue to expose the EPU to this test. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(6) *Acceleration and deceleration runs.* Thirty minutes of accelerations and decelerations, consisting of six cycles from ~~idling~~ 10% power to rated takeoff power and maintained at the takeoff power lever position for 30 seconds and at the ~~idle~~ 10% power lever position for approximately 41/2minutes. In complying with this paragraph, the power control lever must be moved from one extreme position to the other in not more than one second. If, however, different regimes of control operations are incorporated that necessitate scheduling of the power control lever motion from one extreme position to the other, then a longer period of time is acceptable, but not more than two seconds.	*Unchanged* [Logic is intended to parallel reasons cited above. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(7) *Starts.* One hundred starts must be made.~~, of which 25 starts must be preceded by at least a two-hour engine shutdown. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time, before attempting a normal start. There must be at least 10 normal restarts with not longer than 15 minutes since engine shutdown. The remaining starts may be made~~ approximately 50 of these starts must be performed after completing the 150 hours of endurance testing.	*Modified* [Logic is intended to parallel reasons cited above.]
(d) *Rotorcraft or VTOL EPUs for which a continuous OEI rating is desired.* For each rotorcraft or VTOL EPU for which a continuous OEI power rating is desired, the applicant must conduct the following series of tests:	*Modified* [It is very logical VTOLs will seek a 30-minute OEI power rating.]
(1) *Takeoff and idling.* One hour of alternate 5-minute periods at rated takeoff power and at ~~idling~~ 10% power. The developed powers at takeoff and ~~idling~~ 10% power conditions and their corresponding rotor speed ~~and gas temperature~~ conditions must be as established by the power control in accordance with the schedule established by the manufacturer. During any one period the rotor speed and power may be controlled manually while taking data to check performance. ~~For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at rated takeoff power must be at the augmented power rating.~~ In changing the power setting after each period, the power control lever must be moved in the manner prescribed in paragraph (c)(5) of this section.	*Modified* [Logic is intended to parallel reasons cited above. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(2) Rated maximum continuous and takeoff power. Thirty minutes at—	*Unchanged* [It is logical to continue to expose the EPU to this test.]

Subpart F—Block Tests; Turbine Aircraft Engines	**Notes**
(i) Rated maximum continuous power during fifteen of the twenty-five 6-hour endurance test cycles; and	*Unchanged*
(ii) Rated takeoff power during ten of the twenty-five 6-hour endurance test cycles.	*Unchanged*
(3) Rated continuous OEI power. One hour at rated continuous OEI power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(4) Rated maximum continuous power. One hour at rated maximum continuous power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(5) *Incremental cruise power.* Two hours at the successive power lever positions corresponding with not less than 12 approximately equal speed and time increments between maximum continuous EPU rotational speed and ~~ground or minimum idle~~ 46% rotational speed. For EPUs operating at constant speed, power may be varied in place of speed. If there are significant peak vibrations anywhere between ground idle and maximum continuous conditions, the number of increments chosen must be changed to increase the amount of running conducted while being subjected to the peak vibrations up to not more than 50 percent of the total time spent in incremental running.	*Modified* [It is logical to continue to expose the EPU to this test. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(6) *Acceleration and deceleration runs.* Thirty minutes of accelerations and decelerations, consisting of six cycles from ~~idling~~ 10% power to rated takeoff power and maintained at the takeoff power lever position for 30 seconds and at the ~~idling~~ 10% power lever position for approximately 41/2minutes. In complying with this paragraph, the power control lever must be moved from one extreme position to the other in not more than 1 second, except that if different regimes of control operations are incorporated necessitating scheduling of the power control lever motion in going from one extreme position to the other, a longer period of time is acceptable, but not more than 2 seconds.	*Unchanged* [Logic is intended to parallel reasons cited above. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(7) *Starts.* One hundred starts must be made.~~, of which 25 starts must be preceded by at least a two-hour engine shutdown. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time, before attempting a normal start. There must be at least 10 normal restarts with not longer than 15 minutes since engine shutdown. The remaining starts may be made~~ approximately 50 of these starts must be performed after completing the 150 hours of endurance testing.	*Modified* [It is very logical VTOLs will seek a 2½-minute OEI power rating.]
(e) *Rotorcraft or VTOL EPUs for which a 2½ -minute OEI power rating is desired.* For each rotorcraft or VTOL EPU for which a 2½ -minute OEI power rating is desired, the applicant must conduct the following series of tests:	*Modified* [It is very logical VTOLs will seek a 2½-minute OEI power rating.]
(1) *Takeoff, 2½-minute OEI, and idling.* One hour of alternate 5-minute periods at rated takeoff power and at ~~idling~~ 10% power except that, during the third and sixth takeoff power periods, only 2½ minutes need be conducted at rated takeoff power, and the remaining 2½ minutes must be conducted at rated 2½ -minute OEI power. The developed powers at takeoff, 2½ -minute OEI, and ~~idling~~ 10% power conditions and their corresponding rotor speed ~~and gas temperature~~ conditions must be as established by the power control in accordance with the schedule established by the manufacturer. The applicant may, during any one period, control manually the rotor speed and power while taking data to check performance. ~~For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at rated takeoff power must be at the augmented rating.~~ In changing the power setting after or during each period, the power control lever must be moved in the manner prescribed in paragraph (d)(6) of this section.	*Modified* [Logic is intended to parallel reasons cited above. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(2) The tests required in paragraphs (b)(2) through (b)(6), or (c)(2) through (c)(7), or (d)(2) through (d)(7) of this section, as applicable, except that in one of the 6-hour test sequences, the last 5 minutes of the 30 minutes at takeoff power test period of paragraph (b)(2) of this section, or of the 30 minutes at 30-minute OEI power test period of paragraph (c)(4) of this section, or of the l hour at continuous OEI power test period of paragraph (d)(3) of this section, must be run at 21⁄2 -minute OEI power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]

Subpart F—Block Tests; Turbine Aircraft Engines	Notes
(f) *Rotorcraft or VTOL EPUs for which 30-second OEI and 2-minute OEI ratings are desired.* For each rotorcraft or VTOL EPU for which 30-second OEI and 2-minute OEI power ratings are desired, and following completion of the tests under paragraphs (b), (c), (d), or (e) of this section, the applicant may disassemble the tested EPU to the extent necessary to show compliance with the requirements of §33.93(a). The tested EPU must then be reassembled using the same parts used during the test runs of paragraphs (b), (c), (d), or (e) of this section, except those parts described as consumables in the Instructions for Continued Airworthiness. Additionally, the tests required in paragraphs (f)(1) through (f)(8) of this section must be run continuously. If a stop occurs during these tests, the interrupted sequence must be repeated unless the applicant shows that the severity of the test would not be reduced if it were continued. The applicant must conduct the following test sequence four times, for a total time of not less than 120 minutes:	*Modified* [It is very logical VTOLs will seek both a 30-second and 2-minute OEI power rating.]
(1) Takeoff power. Three minutes at rated takeoff power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(2) 30-second OEI power. Thirty seconds at rated 30-second OEI power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(3) 2-minute OEI power. Two minutes at rated 2-minute OEI power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(4) 30-minute OEI power, continuous OEI power, or maximum continuous power. Five minutes at whichever is the greatest of rated 30-minute OEI power, rated continuous OEI power, or rated maximum continuous power, except that, during the first test sequence, this period shall be 65 minutes. However, where the greatest rated power is 30-minute OEI power, that sixty-five minute period shall consist of 30 minutes at 30-minute OEI power followed by 35 minutes at whichever is the greater of continuous OEI power or maximum continuous power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(5) 50 percent takeoff power. One minute at 50 percent takeoff power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(6) 30-second OEI power. Thirty seconds at rated 30-second OEI power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(7) 2-minute OEI power. Two minutes at rated 2-minute OEI power.	*Unchanged* [It is logical to continue to expose the EPU to this test.]
(8) *Idle.* One minute at ~~flight idle~~ 10% power.	*Unchanged* [It is logical to continue to expose the EPU to this test. "Idling" conditions are established on the basis of typical propeller taxi conditions. 10% power typically corresponds with 46% RPM.]
(g) Supersonic aircraft engines. For each engine type certificated for use on supersonic aircraft the applicant must conduct the following:	*Removed* [Not applicable]
(1) Subsonic test under sea level ambient atmospheric conditions. Thirty runs of one hour each must be made, consisting of—	*Removed* [Not applicable]
(i) Two periods of 5 minutes at rated takeoff augmented thrust each followed by 5 minutes at idle thrust;	*Removed* [Not applicable]
(ii) One period of 5 minutes at rated takeoff thrust followed by 5 minutes at not more than 15 percent of rated takeoff thrust;	*Removed* [Not applicable]
(iii) One period of 10 minutes at rated takeoff augmented thrust followed by 2 minutes at idle thrust, except that if rated maximum continuous augmented thrust is lower than rated takeoff augmented thrust, 5 of the 10-minute periods must be at rated maximum continuous augmented thrust; and	*Removed* [Not applicable]
(iv) Six periods of 1 minute at rated takeoff augmented thrust each followed by 2 minutes, including acceleration and deceleration time, at idle thrust.	*Removed* [Not applicable]

Subpart F—Block Tests; Turbine Aircraft Engines	**Notes**
(2) Simulated supersonic test. Each run of the simulated supersonic test must be preceded by changing the inlet air temperature and pressure from that attained at subsonic condition to the temperature and pressure attained at supersonic velocity, and must be followed by a return to the temperature attained at subsonic condition. Thirty runs of 4 hours each must be made, consisting of—	*Removed* [Not applicable]
(i) One period of 30 minutes at the thrust obtained with the power control lever set at the position for rated maximum continuous augmented thrust followed by 10 minutes at the thrust obtained with the power control lever set at the position for 90 percent of rated maximum continuous augmented thrust. The end of this period in the first five runs must be made with the induction air temperature at the limiting condition of transient overtemperature, but need not be repeated during the periods specified in paragraphs (g)(2)(ii) through (iv) of this section;	*Removed* [Not applicable]
(ii) One period repeating the run specified in paragraph (g)(2)(i) of this section, except that it must be followed by 10 minutes at the thrust obtained with the power control lever set at the position for 80 percent of rated maximum continuous augmented thrust;	*Removed* [Not applicable]
(iii) One period repeating the run specified in paragraph (g)(2)(i) of this section, except that it must be followed by 10 minutes at the thrust obtained with the power control lever set at the position for 60 percent of rated maximum continuous augmented thrust and then 10 minutes at not more than 15 percent of rated takeoff thrust;	*Removed* [Not applicable]
(iv) One period repeating the runs specified in paragraphs (g)(2)(i) and (ii) of this section; and	*Removed* [Not applicable]
(v) One period of 30 minutes with 25 of the runs made at the thrust obtained with the power control lever set at the position for rated maximum continuous augmented thrust, each followed by idle thrust and with the remaining 5 runs at the thrust obtained with the power control lever set at the position for rated maximum continuous augmented thrust for 25 minutes each, followed by subsonic operation at not more than 15 percent or rated takeoff thrust and accelerated to rated takeoff thrust for 5 minutes using hot fuel.	*Removed* [Not applicable]
(3) Starts. One hundred starts must be made, of which 25 starts must be preceded by an engine shutdown of at least 2 hours. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time before attempting a normal start. At least 10 starts must be normal restarts, each made no later than 15 minutes after engine shutdown. The starts may be made at any time, including the period of endurance testing. [ref: Doc. No. 3025, 29 FR 7453, June 10, 1964, as amended by Amdt. 33-3, 32 FR 3737, Mar. 4, 1967; Amdt. 33-6, 39 FR 35468, Oct. 1, 1974; Amdt. 33-10, 49 FR 6853, Feb. 23, 1984; Amdt. 33-12, 53 FR 34220, Sept. 2, 1988; Amdt. 33-18, 61 FR 31328, June 19, 1996; Amdt. 33-25, 73 FR 48123, Aug. 18, 2008; Amdt. 33-30, 74 FR 45311, Sept. 2, 2009; Amdt. 33-32, 77 FR 22187, Apr. 13, 2012]	*Removed* [Not applicable]
§33.88 EPU overtemperature test.	
Each EPU electric motor must be run at least for the time to reach steady state temperatures plus 1 hour of continuous operation, ~~Each EPU must run for 5 minutes~~ at maximum permissible rpm, ~~with the gas temperature at least 75 °F (42 °C) higher than the maximum rating's steady-state operating limit~~, ~~excluding~~ including maximum values of rpm ~~and gas~~ temperature associated with the 30-second OEI and 2-minute OEI ratings. Per each rating, the stabilized permanent magnet temperature shall be at least 15 °C beyond the maximum expected temperature associated with this rating. Following this run, the ~~turbine~~ EPU electric motor rotor assembly must be within serviceable limits.	*Modified*. [Elements of ASTM F3338-20 Section 5.21.6 have been incorporated into the existing regulatory language. Operation at maximum permissible rating is necessary to ensure proper accounting for eddy current and windage thermal loads. We disagree with the disclaimers in the ASTM standard that the test temperatures "must not violate the physical limitation of the permanent magnet material (Curie-temperature including sufficient safety margin." The purpose of this test is to establish that margin exists.]

Subpart F—Block Tests; Turbine Aircraft Engines	Notes
(b) In addition to the test requirements in paragraph (a) of this section, each engine for which 30-second OEI and 2-minute OEI ratings are desired, that incorporates a means for automatic temperature control within its operating limitations in accordance with §33.28(k), must run for a period of 4 minutes at the maximum power-on rpm with the gas temperature at least 35 °F (19 °C) higher than the maximum operating limit at 30-second OEI rating. Following this run, the turbine assembly may exhibit distress beyond the limits for an overtemperature condition provided the engine is shown by analysis or test, as found necessary by the FAA, to maintain the integrity of the turbine assembly.	*Removed* [Not applicable]
(c) A separate test vehicle may be used for each test condition. [ref: Doc. No. 26019, 61 FR 31329, June 19, 1996, as amended by Amendment 33-25, 73 FR 48124, Aug. 18, 2008; Amendment 33-26, 73 FR 48285, Aug. 19, 2008]	*Removed* [Not applicable]
§33.90 Initial maintenance inspection test.	*Unchanged* [A review of the original rulemaking explanation (14 CFR 33 Amendment 6) shows that the addition of magniX special condition 26, Durability demonstration, fulfills the intent of this Regulation.]
Each applicant, except an applicant for an engine being type certificated through amendment of an existing type certificate or through supplemental type certification procedures, must complete one of the following tests on an engine that substantially conforms to the type design to establish when the initial maintenance inspection is required:	
(a) An approved engine test that simulates the conditions in which the engine is expected to operate in service, including typical start-stop cycles.	
(b) An approved engine test conducted in accordance with Sec. 33.201 (c) through (f).	*Removed* [Not applicable, applies to ETOPS engines.]
§33.91 Engine system and component tests.	Unchanged [Retained as reference for magniX special condition 27.]
(a) For those systems or components that cannot be adequately substantiated in accordance with endurance testing of §33.87, the applicant must conduct additional tests to demonstrate that the systems or components are able to perform the intended functions in all declared environmental and operating conditions.	
(b) Temperature limits must be established for those components that require temperature controlling provisions in the aircraft installation to assure satisfactory functioning, reliability, and durability.	
(c) Each unpressurized hydraulic fluid tank may not fail or leak when subjected to a maximum operating temperature and an internal pressure of 5 p.s.i., and each pressurized hydraulic fluid tank must meet the requirements of §33.64.	
(d) For an engine type certificated for use in supersonic aircraft, the systems, safety devices, and external components that may fail because of operation at maximum and minimum operating temperatures must be identified and tested at maximum and minimum operating temperatures and while temperature and other operating conditions are cycled between maximum and minimum operating values. [ref: Doc. No. 3025, 29 FR 7453, June 10, 1964, as amended by Amendment 33-6, 39 FR 35469, Oct. 1, 1974; Amendment 33-26, 73 FR 48285, Aug. 19, 2008; Amendment 33-27, 73 FR 55437, Sept. 25, 2008; Amendment 33-27, 73 FR 57235, Oct. 2, 2008]	*Removed* [Not applicable]
Sec. 33.92 Rotor locking tests.	*Unchanged* [Retained as reference for magniX special condition 28.]
If continued rotation is prevented by a means to lock the rotor(s), the engine must be subjected to a test that includes 25 operations of this means under the following conditions:	
(a) The engine must be shut down from rated maximum continuous thrust or power; and	
(b) The means for stopping and locking the rotor(s) must be operated as specified in the engine operating instructions while being subjected to the maximum torque that could result from continued flight in this condition; and	
(c) Following rotor locking, the rotor(s) must be held stationary under these conditions for five minutes for each of the 25 operations.	
Sec. 33.93 Teardown inspection.	

Subpart F—Block Tests; Turbine Aircraft Engines	Notes
(a) After completing the endurance testing of Sec. 33.87(b), (c), (d), (e), or (g) of this part, each engine must be completely disassembled, and (1) 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 (2) Each engine part 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 Sec. 33.4.	*Unchanged* [Retained as reference for magniX special condition 29.]
(b) After completing the endurance testing of Sec. 33.87(f), each engine must be completely disassembled, and (1) 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 (2) Each engine may exhibit deterioration in excess of that permitted in paragraph (a)(2) of this section, including some engine parts or components that may be unsuitable for further use. The applicant must show by inspection, analysis, test, or by any combination thereof as found necessary by the FAA, that structural integrity of the engine is maintained; or	
(c) In lieu of compliance with paragraph (b) of this section, each engine for which the 30-second OEI and 2-minute OEI ratings are desired, may be subjected to the endurance testing of Secs. 33.87(b), (c), (d), or (e) of this part, and followed by the testing of Sec. 33.87(f), without intervening disassembly and inspection. However, the engine must comply with paragraph (a) of this section after completing the endurance testing of Sec. 33.87(f).	
Sec. 33.94 Blade containment and rotor unbalance tests.	*Unchanged* [Retained as reference for magniX special condition 30.]
(a) Except as provided in paragraph (b) of this section, it must be demonstrated by engine tests that the engine is capable of containing damage without catching fire and without failure of its mounting attachments when operated for at least 15 seconds, unless the resulting engine damage induces a self shutdown, after each of the following events: (1) Failure of the most critical compressor or fan blade while operating at maximum permissible r.p.m. The blade failure must occur at the outermost retention groove or, for integrally-bladed rotor discs, at least 80 percent of the blade must fail. (2) Failure of the most critical turbine blade while operating at maximum permissible r.p.m. The blade failure must occur at the outermost retention groove or, for integrally-bladed rotor discs, at least 80 percent of the blade must fail. The most critical turbine blade must be determined by considering turbine blade weight and the strength of the adjacent turbine case at case temperatures and pressures associated with operation at maximum permissible r.p.m.	
(b) Analysis based on rig testing, component testing, or service experience may be substituted for one of the engine tests prescribed in paragraphs (a)(1) and (a)(2) of this section if-- (1) That test, of the two prescribed, produces the least rotor unbalance; and (2) The analysis is shown to be equivalent to the test.	
Sec. 33.95 Engine-propeller systems tests.	*Unchanged* [Retained as reference for magniX special condition 31.]
If the engine is designed to operate with a propeller, the following tests must be made with a representative propeller installed by either including the tests in the endurance run or otherwise performing them in a manner acceptable to the Administrator:	
(a) Feathering operation: 25 cycles.	
(b) Negative torque and thrust system operation: 25 cycles from [rated] maximum continuous power.	
(c) Automatic decoupler operation: 25 cycles from [rated] maximum continuous power (if repeated decoupling and recoupling in service is the intended function of the device).	
(d) Reverse thrust operation: 175 cycles from the flight-idle position to full reverse and 25 cycles at [rated] maximum continuous power from full forward to full reverse thrust. At the end of each cycle the propeller must be operated in reverse pitch for a period of 30 seconds at the maximum rotational speed and power specified by the applicant for reverse pitch operation.	
Sec. 33.96 Engine tests in auxiliary power unit (APU) mode.	*Removed* [Not applicable]
Sec. 33.97 Thrust reversers.	*Removed* [Not applicable]

Subpart F—Block Tests; Turbine Aircraft Engines	Notes
(a) If the engine incorporates a reverser, the endurance, calibration, operation, and vibration tests prescribed in this subpart must be run with the reverser installed. In complying with this section, the power control lever must be moved from one extreme position to the other in not more than one second except, if regimes of control operations are incorporated necessitating scheduling of the power-control lever motion in going from one extreme position to the other, a longer period of time is acceptable but not more than three seconds. In addition, the test prescribed in paragraph (b) must be made. This test may be scheduled as part of the endurance run.	
(b) 175 reversals must be made from flight-idle forward thrust to maximum reverse thrust and 25 reversals must be made from [rated takeoff thrust] to maximum reverse thrust. After each reversal, the reverser must be operated at full reverse thrust for a period of one minute, except that, in the case of a reverser intended for use only as a braking means on the ground, the reverser need only be operated at full reverse thrust for 30 seconds.	
Sec. 33.99 General conduct of block tests.	
(a) Each applicant may, in making a block test, use separate engines of identical design and construction in the vibration, calibration, 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) Each 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 [Sec. 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 must be subjected to any additional tests the Administrator finds necessary.	
(c) Each applicant must furnish all testing facilities, including equipment and competent personnel, to conduct the block tests.	

3.8.4 ASTM F3338, Specification for Design of Electric Propulsion Units for General Aviation Aircraft, §5.12-5.26

The following sections of ASTM F3338 refer to §5.12 Vibration; §5.13, EPU System and Component Tests; §5.14, Stress Analysis; §5.15, EPU Life Limited Parts and Critical Parts; §5.16, Lubrication System; §5.17, Continued Rotation; §5.18, Pressure Loads; §5.19, Safety Analysis; §5.20, Ingestion; §5.21, Combination Tests; §5.22, Rotor Locking Tests; §5.23, Teardown Inspection; §5.24, Containment; §5.25, EPU-Variable Pitch Propeller or Fan Systems Tests; and §5.26, Tests for Fixed-Pitch Propellers or Fans when Included in the EPU Type Certificate.

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5.12 Vibration—The EPU shall be designed and constructed to function throughout its normal operating range of rotor speeds and EPU output brake power without inducing excessive stress in any of the EPU parts because of vibration and without imparting excessive vibration forces to the aircraft structure. In addition to historical sources of vibration such as aerodynamic excitation, analysis of rotating component resonance induced by field-excitation, should also be assessed,	Listed for reference only
5.13 EPU System and Component Tests:	
5.13.1 For those systems and components that cannot be adequately substantiated in accordance with endurance testing, additional tests shall be conducted to demonstrate that systems or components are able to perform the intended functions in all declared environmental and operating conditions.	
5.13.2 Temperature limits shall be established for each component that requires temperature-controlling provisions in the aircraft installation to assure satisfactory functioning, reliability, and durability.	
5.13.3 Voltage and current limits shall be established for each component that requires voltage or current controlling provisions, or both, in the aircraft installation to assure satisfactory functioning, reliability, and durability.	
5.14 Stress Analysis:	

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5.14.1 A mechanical stress analysis, to show complete understanding of the operating conditions that limit the design, shall be performed on each EPU showing the design safety margin of each rotor, stator, and housing of the EPU.	Listed for reference only
5.14.2 An electrical stress analysis shall be performed on each EPU showing the electrical design safety margin of each electrical component above 220 VAC or 48 VDC.	
5.14.3 Testing would be a suitable means of compliance with the "stress analysis" requirement, if it can be shown that all of the limiting conditions have been tested.	
5.15 EPU Life Limited Parts and Critical Parts:	
5.15.1 The manufacturer should determine whether the rotating/moving components, bearing, shafts, nonredundant mount components should be critical parts or life-limited parts, as defined below:	
5.15.1.1 A "critical part" is a part whose primary failure could cause a hazardous effect, but whose failure mechanisms are limited to high cycle fatigue or overload such that the part is not required to be removed by a certain number of flight cycles, EPU operating hours, etc.	
5.15.1.2 A "life-limited part" is a critical part whose failure mechanisms include low-cycle fatigue, creep, or other mechanisms such that the part shall be removed after accumulating a certain number of flight cycles, operating hours, etc. to ensure an acceptable level of safety. EPU life-limited parts may include, but are not limited to, rotating/moving components, bearings, shafts, nonredundant mount components, high-voltage electrical components or the entire EPU.	
5.15.2 Requirements for Critical Parts—The integrity of each critical part identified by the safety analysis shall be established by:	Listed for reference only
5.15.2.1 A defined engineering process for ensuring the integrity of the critical part throughout its service life,	
5.15.2.2 A defined manufacturing process that identifies the requirements to consistently produce the critical part as required by the engineering process, and	
5.15.2.3 A defined service management process that identifies the continued airworthiness requirements of the critical part as required by the engineering process.	
5.15.3 Requirements for Life-limited Parts—Operating limitations shall be established by an approved procedure that specifies the maximum allowable number of flight cycles for each life-limited part. The manufacturer will establish the integrity of each life-limited part by:	
5.15.3.1 An engineering plan that contains the steps required to ensure each life-limited part is withdrawn from service at an approved life before hazardous effects can occur. These steps include validated analysis, test, or service experience which ensures that the combination of loads, material properties, environmental influences and operating conditions, including the effects of other parts influencing these parameters, are sufficiently well known and predictable so that the operating limitations can be established and maintained for each life-limited part. Manufacturers shall perform appropriate damage tolerance assessments to address the potential for failure from material, manufacturing, and service induced anomalies within the approved life of the part. Manufacturers shall publish a list of life-limited parts and the approved life for each part in the Airworthiness Limitations section of the Instructions for Continued Airworthiness.	
5.15.3.2 A manufacturing plan that identifies the specific manufacturing constraints necessary to consistently produce each life-limited part with the attributes required by the engineering plan.	
5.15.3.3 A service management plan that defines in-service processes for maintenance inspection, overhaul, repair, preservation, and the replacement of parts but excludes preventive maintenance.Subcommittee: F39.02 Standard: F2799 and the limitations to repair for each life-limited part that will maintain attributes consistent with those required by the engineering plan. These processes and limitations will become part of the Instructions for Continued Airworthiness.	
5.15.3.4 Paragraphs 5.15.1 through 5.15.3 do not apply if the manufacturer can show that a failed hub, rotor, or blade retention component will not create debris with sufficient energy to penetrate the thruster or e-motor casing, and provided all contained failures are assigned a severity of major or less. However, energy levels and trajectories of fragments resulting from a failed hub, rotor, or blade retention component that lie outside the duct shall be defined.	
5.16 Lubrication System— The lubrication system of the EPU shall be designed and constructed so that it will function properly in all flight attitudes and atmospheric conditions in which the aircraft is expected to operate.	
5.17 Continued Rotation:	

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5.17.1 If any of the EPU main rotating systems continue to rotate after the EPU is shut down for any reason while in flight, and if means to prevent that continued rotation are not provided, then any continued rotation during the maximum period of flight, and in the flight conditions expected to occur with that EPU inoperative, may not result in any hazardous EPU conditions defined in the Safety Analysis requirements section.	Listed for reference only.
5.17.2 EPU configurations where the EPU can be back-driven by the thruster during power-off operation shall be designed in such a way that either:	
5.17.2.1 The back-EMF generated during back-drive will not cause catastrophic failure of the EPU and associated systems in case of shorted windings for a time consistent with the applicable continued operation, or	
5.17.2.2 If means are provided to decouple the thruster from the motor during power off operation or to prevent back-drive. The safety of these means shall be analyzed and demonstrated not to introduce additional hazards in case of malfunctioning or inadvertent operation.	
5.18 *Pressure Loads*—All static parts subject to significant gas or liquid pressure loads for a stabilized period of 1 min shall not:	
5.18.1 Exhibit permanent distortion beyond serviceable limits or exhibit leakage that could create a hazardous condition when subjected to the greater of the following pressures: (1) 1.1 times the maximum working pressure; (2) 1.33 times the normal working pressure; or (3) 5 psi (35 kPa) above the normal working pressure.	
5.18.2 Exhibit fracture or burst when subjected to the greater of the following pressures: (1) 1.15 times the maximum possible pressure; (2) 1.5 times the maximum working pressure; or (3) 5 psi (35 kPa) above the maximum possible pressure.	
5.18.3 Compliance with this subsection shall take into account: (1) The operating temperature of the part; (2) Any other significant static loads in addition to pressure loads; (3) Minimum properties representative of both the material and the processes used in the construction of the part; and (4) Any adverse geometry conditions allowed by the type design.	
5.19 Safety Analysis:	
5.19.1 The EPU design shall be analyzed, including the control, to assess the likely consequences of all failures that can reasonably be expected to occur. This analysis will include, if applicable:	
5.19.1.1 Aircraft-level devices and procedures assumed to be associated with a typical installation. All assumptions shall be stated in the analysis.	
5.19.1.2 Secondary failures and latent failures that have EPU level consequences.	
5.19.1.3 Multiple failures referred to in paragraph 5.19.4 of this section or that result in the hazardous EPU effects defined in paragraph 3.2.4.	
5.19.2 Failures that could result in major EPU effects or hazardous EPU effects, shall be summarized with estimates of the probability of occurrence of those effects. Any EPU part, the failure of which could reasonably result in a hazardous EPU effect, shall be clearly identified in this summary.	
5.19.3 The primary failures of certain single EPU elements cannot be sensibly estimated in numerical terms. If the failure of such elements is likely to result in hazardous EPU effects, those elements shall be identified as EPU critical parts. EPU critical parts should meet the prescribed integrity specifications of 5.15. These instances shall be stated in the safety analysis.	
5.19.4 If reliance is placed on a safety system to prevent a failure from progressing to hazardous EPU effects, the possibility of a safety system failure in combination with a basic EPU failure shall be included in the analysis. Such a safety system may include safety devices, instrumentation, early warning devices, maintenance checks, and other similar equipment or procedures. Requirements for mitigation means, that are not part of the EPU, shall be specified in the installation and operation instructions.	
5.19.5 If the safety analysis includes one or more of the following items, those items shall be identified in the analysis and substantiated.	
5.19.5.1 Maintenance actions being carried out at stated intervals. This includes the verification of the serviceability of items that could fail in a latent manner. When necessary to prevent hazardous EPU effects, these maintenance actions and intervals shall be published in the Instructions for Continued Airworthiness and relevant manuals. Additionally, if errors in maintenance of the EPU, including the control, could lead to hazardous EPU effects, the appropriate procedures shall be included in the relevant EPU manuals.	Listed for reference only

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5.19.5.2 Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details shall be published in the appropriate manual.	Listed for reference only
5.19.5.3 The provisions of specific instrumentation not otherwise required.	
5.19.5.4 Flight crew actions to be specified in the operating instructions.	
5.19.6 Unless otherwise approved by the CAA and stated in the safety analysis, in accordance with this specification, the following failure definitions apply to the EPU:	
5.19.6.1 An EPU failure in which the only consequence is partial or complete loss of brake power from the EPU will be regarded as a minor EPU effect.	
5.19.6.2 An effect whose severity falls between those effects covered in paragraphs 5.19.6.1 and the definition of Hazardous EPU Effects in 3.2.4 will be regarded as a major EPU effect.	
5.20 Ingestion: NOTE 4: Foreign object ingestion is less of a concern for EPUs than for combustion or turbine engines as the incoming air is not needed for a combustion process. Thus, concerns around ingestion for EPUs focus on cooling blockage and structural damage.	
5.20.1 A cooling failure as the result of blocked cooling passages due to a bird strike up to 4 lb or hail or ice contamination may be addressed via a design feature. In absence of a design feature to protect the cooling inlet, it shall be shown that loss of cooling will not result in a hazardous EPU effect, or that blockage cannot lead to a cooling failure.	
5.20.2 A component failure should be based on test or analysis, where the EPU will need to be loaded as it is when installed, using resulting loads from a 4 lb bird strike to the propeller or the fan. Components include EPU mounts, EPU bearings, EPU shaft, wires, avionics, and other. The maximum load should be documented in the installation manual.	
5.20.3 The structural damage shall not result in any Hazardous EPU Effects.	
5.20.4 Ingestion of objects into the inlet/EPU (that don't block the cooling passages) shall be shown to not cause EPU damage that could result in a Hazardous EPU Effect, nor should ingestion of an object into the inlet/EPU cause EPU damage that could result in hazardous EPU Effect or conditions, such as: wires shorting out, which could lead to sparks/fire or electrical problems like electrical noise affecting the control system or avionics, or electrical power circuit overloading impacting the battery or other EPUs.	
5.20.5 Water spray shall not result in any hazardous EPU effects throughout the EPU operating range. Spray shall be arranged to deliver water in a manner representative of very heavy rain over the whole frontal area of the EPU including cowling, air intakes, etc., throughout the full running time.	Listed for reference only
5.20.6 For EPU intended to be operated on an aircraft allowed to fly in known icing conditions, a test in icing conditions to demonstrate the proper operation of the engine under the icing condition as defined in CAA rules.	
5.21 Combination Tests:	
5.21.1 EPU design and construction shall minimize the development of an unsafe condition of the EPU between maintenance or overhaul periods defined in the Instructions for Continued Airworthiness, as applicable. NOTE 5: There are a series of tests that are intended to reveal weaknesses in the product for which approval is being sought. These tests are based on many years of experience with aviation products. However, there are aspects of the tests that may need to be customized based on the specific and possibly unique design of the EPU or the intended use of the EPU.	
5.21.2 General Conduct of EPU Tests:	
5.21.2.1 In conducting an EPU test, separate EPUs of identical design and construction may be used in the vibration, calibration, endurance, and operation tests, except that, if a separate EPU is used for the endurance test, it shall be subjected to a calibration check before conducting the endurance test.	
5.21.2.2 Service and minor repairs to the EPU may be made during the tests in accordance with the service and maintenance instructions submitted in the Instructions for Continued Airworthiness. If the frequency of the service is excessive, or the number of stops due to EPU 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 EPU or its parts shall be subjected to any additional tests the CAA finds necessary.	
5.21.2.3 The following are a set of baseline tests. These may be used to form a test sequence and can be accomplished as a combination of test conditions for a sequential test or they may be used individually.	

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5.21.2.4 Upon conclusion of tests conducted to show compliance with this section, each EPU part or individual groups of components shall meet the requirements of the teardown inspection (see 5.23). It should be considered what the ramifications are of findings during teardown. If the tests have been run as a combination sequence and there are findings in teardown it may not be clear which particular test was the source of the finding. This will have to be resolved.	Listed for reference only
5.21.3 Endurance and Durability Test:	Listed for reference only
5.21.3.1 An endurance and durability test of sufficient duration with respect to cycles and brake power settings shall be performed to show that each part of the EPU has been designed and constructed to minimize the development of any unsafe condition of the system between overhaul periods or during the life of the EPU if no overhaul intervals are prescribed. The test time duration, number of cycles, and test schedule definition should provide sufficient demonstration of durability with regard to the failure modes that could result in major EPU effects or hazardous EPU effects. The test schedule shall be justified using validated analytical methods, empirical testing, or experience with EPU or motors with comparable design. During the endurance test, the EPU brake power and the output shaft rotational speed shall be demonstrated at or above 100 % of the rated values. An EPU that is intended to drive a propeller that is type-certificated separately from the EPU shall be fitted for the endurance and durability test with a propeller that thrust-loads the EPU to the maximum thrust which the EPU is designed to resist at each applicable operating condition specified in this section. The endurance and durability test shall be run on an EPU representative of the type design. Any deviation to the type design shall be recorded. It shall be justified that any of the recorded deviations to the type design does not affect the results of the test.	
5.21.3.2 The endurance and durability test shall consist of at least the following elements:	
(1) A run consisting of alternate periods of operation at rated takeoff power and the minimum power and periods of operation at maximum continuous brake power and the minimum brake power, that can be commanded by the control system during operation.	
(2) A series of runs consisting of alternate periods of operation at maximum continuous brake power and successively lower brake power settings. The range of power settings should be selected to expose any deleterious responses or vibration.	
(3) Each period of operation discussed in this section shall be conducted at stabilized values for rotational speed, torque, temperature, and any other parameter deemed to ensure the safety of the EPU to achieve steady state values. At the ratings and duty cycles established in conjunction with 5.3 of this specification, the stabilized temperature for the motor and the motor controller shall be equal to or greater than the temperature associated with this rating.	
5.21.4 Vibration Test:	Listed for reference only
5.21.4.1 Each EPU shall be analyzed to establish that the vibration characteristics of those components that may be subject to mechanically or aerodynamically induced vibratory excitations are acceptable throughout the declared flight envelope. At a minimum, the torsional and bending vibration characteristics of the propeller or fan shaft, over the range of propeller or fan shaft speed and propeller or fan power, under steady state and transient conditions, from the minimum shaft speed that the control system can command during operation to a shaft speed that exceeds the maximum desired speed rating by a sufficient margin to determine the maximum vibratory stresses shall be established. This margin shall be justified using analytical means, prior experience, or empirical data as applicable. The EPU test shall be conducted using, for airplane EPUs, the same configuration of the propeller or fan which is used for the endurance and durability test, and using, for other EPUs, the same configuration of the loading device type which is used for the endurance and durability test.	
5.21.4.2 The EPU test shall cover the ranges of brake power for each rotating component system, corresponding to operations throughout the range of ambient conditions in the declared flight envelope, from the minimum obtainable rotational speed that can be commanded by the control system up to 103 % of the maximum rotational speed permitted for rating periods of 2 min or longer, and up to 100 % of all other permitted rotational speeds, including those that are overspeeds. If there is any indication of a stress peak arising at the highest of those required rotational speeds, the EPU test shall be extended sufficiently to reveal the maximum stress values present, except that the extension need not cover more than a further 2 percentage points increase beyond those speeds.	

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5.21.4.3 Except as provided by paragraph 5.21.4.4 of this section, the vibration stresses associated with the vibration characteristics determined under this section, when combined with the appropriate steady state stresses, shall be less than the endurance limits of the materials concerned, after making due allowances for operating conditions for the permitted variations in properties of the materials. The suitability of these stress margins shall be justified for each part evaluated. If the maximum stress in the shaft cannot be shown to be below the endurance limit by measurement, the vibration frequency and amplitude shall be measured. The EPU shall be run at the condition producing the peak amplitude for a number of stress reversals sufficient to ensure that fatigue failure will not occur in service. Alternatively, the EPU may be run at a condition producing peak amplitude until 10 million stress reversals have been sustained without fatigue failure for steel shafts and, for other shafts, until it is shown that fatigue will not occur within the endurance limit stress of the material. If it is determined that certain operating conditions, or ranges, need to be limited, operating and installation limitations shall be established. Operating and installation limitations shall be established for shafts made from materials that do not have endurance limits.	*NOTE:* [Elements of ASTM F3338-20 Section 5.21.4.3 have been reviewed and the opinion is that regulatory requirements based on reciprocating engine block testing (14 CFR 33.43(b) are not appropriate for EPUs in this circumstance. Instead, recommend reliance on 14 CFR 33.83(c).]
(1) The purpose of this discussion is defined as follows: Endurance limit. The alternating stress that can be repeated for an infinite number of cycles without material fatigue failure. To demonstrate endurance limit for metallic materials, 10^7 cycles have generally been accepted as the test proxy for an "infinite" number of cycles. The endurance limit depends on the steady-state stresses, temperatures, and other factors.	Listed for reference only
5.21.4.4 The effects on vibration characteristics of excitation forces caused by fault conditions (such as, but not limited to, out of balance rotating components, local airflow blockage, etc.) or by excitation caused by the electromagnetic fields shall be evaluated by test or analysis, or by reference to previous experience and shall be shown not to create a hazardous condition for the EPU.	Listed for reference only
5.21.4.5 Compliance with this section shall be substantiated for each specific installation configuration that can affect the vibration characteristics of the EPU. If these vibration effects cannot be fully investigated during EPU certification, the methods by which they can be evaluated and methods by which compliance can be shown shall be substantiated and defined in the installation instructions required by 5.2.	Listed for reference only
5.21.5 EPU Overtorque Test:	
5.21.5.1 When approval is sought for a transient maximum EPU overtorque, it should be shown that the EPU is capable of further operation at the maximum EPU overtorque condition without maintenance action. This may be accomplished by test, analysis based on test, or similarity of sufficient duration and operating conditions to substantiate the overtorque condition.	*NOTE:* [While elements of ASTM F3338-20 Section 5.21.5.1 are appropriate, opinion is that existing regulatory requirements based on traditional and long-standing OEI ratings remains appropriate (reference 14 CFR 33.85(d) and related OEI testing performed under 14 CFR 33.87).
(1) The test may be run as part of the endurance test. Alternatively, tests may be performed on a complete EPU or equivalent testing may be performed on individual groups of components.	Listed for reference only
(2) Upon conclusion of tests conducted to show compliance with this section, each EPU part or individual groups of components shall meet the requirements of the teardown inspection (see 5.23).	Listed for reference only
(3) The total run-time at the maximum EPU overtorque to be approved shall not be less than the total cumulative run time per the selected duty cycle(s) and corresponding overtorque values. This may be done in separate runs, each being of at least that duration corresponding to one single duty cycle of each type.	Listed for reference only
(4) An EPU shaft rotational speed equal to the highest speed at which the maximum overtorque can occur in service. The test speed may not be more than the maximum permissible working speed of the EPU.	Listed for reference only
(5) All EPU major components at maximum steady state temperature approved for use in compliance with the selected duty cycle(s) for type rating.	Listed for reference only
5.21.6 EPU Over Temperature Test:	

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5.20.6.1 Each EPU shall be run at least for the time to reach steady state temperatures plus 1 h of continuous operation at each of the rated conditions for any continuous, periodic, or non-periodic duty rating, including ratings for short time duty.	Operation at maximum permissible rating is necessary to ensure proper accounting for eddy current and windage thermal loads. Disagree with the disclaimers in the ASTM standard that the test temperatures “must not violate the physical limitation of the permanent magnet material (Curie-temperature including sufficient safety margin.” The purpose of this test is to establish that margin exists.
5.21.6.2 Per each rating, the stabilized permanent magnet temperature shall be at least 15 °C beyond the maximum expected temperature associated with this rating, however this shall not violate the physical limitation of the permanent magnet material (curie-temperature) including sufficient safety margin. The safety margin shall be justified.	
5.21.6.3 Upon completion of all rating over temperature tests, the EPU including the rotor permanent magnets, if applicable, shall be within serviceable limits.	
5.21.7 Calibration Tests:	Listed for reference only
5.21.7.1 Each EPU shall be subjected to those tests necessary to establish its power characteristics and the conditions for the endurance and durability test specified in this section. The results of the power characteristics calibration tests form the basis for establishing the characteristics of the EPU over its entire operating range of speeds, torques, and ambient conditions.	Listed for reference only
5.21.7.2 A mechanical and electric power check shall be accomplished on the endurance and durability test EPU after the endurance and durability test described in this section and any change in mechanical and electrical power characteristics which occurs during the endurance and durability test shall be determined. Measurements taken during the final portion of the endurance and durability test may be used in showing compliance with the requirement of this paragraph.	Listed for reference only
5.21.7.3 In showing compliance with this paragraph, each condition shall stabilize before measurements are taken.	Listed for reference only
5.21.8 Operation Test:	Elements of ASTM F3338-20 Section2 5.21.7 and 5.21.9 have been incorporated into the existing regulatory language. However, the test requirements have been expanded to demonstrate both EPU accelerations and decelerations. The Operation Test (5.21.8) and the Power Response (5.21.9) tests have been combined in the Regulation.
5.21.8.1 The operation test shall include testing to demonstrate:	
(1) Energizing, starting, stopping, idling, acceleration, overspeeding, with loading representative of the intended installation;	
(2) Compliance with the EPU response requirements of paragraph 5.21.9.1;	
(3) That the EPU has safe operating characteristics throughout its specified operating envelope. The evaluation should include an assessment of thermal and electrical system performance since certain attributes have temperature and altitude dependencies. For the electrical system this would include failure inducing phenomena such as: partial discharge, corona arcing, and dielectric breakdown.	Elements of ASTM F3338-20 Section2 5.21.7 and 5.21.9 have been incorporated into the existing regulatory language. However, the test requirements have been expanded to demonstrate both EPU accelerations and
5.21.9 Brake Power Response:	
5.21.9.1 The design and construction of the EPU shall enable an increase:	
(1) From minimum to the highest rated power without detrimental factors occurring to the EPU, whenever the setting of the control system command is increased; and	

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(2) From the minimum obtainable brake power that can be commanded by the control system to the highest rated power within a time interval determined to be sufficient for safe aircraft operation. The power response shall occur from a stabilized condition.	decelerations. The Operation Test (5.21.8) and the Power Response (5.21.9) tests have been combined in the Regulation.
5.22 Rotor Locking Tests:	Listed for reference only
5.22.1 If continued rotation is prevented by a means to lock the rotor(s), the EPU shall be subjected to a test that includes repeated operations to sufficiently establish reliable performance. The number of repeated unlocking operations shall be justified, or 25 cycles will be performed. This testing shall be performed under the following conditions:	
5.22.1.1 The EPU shall be shut down from rated maximum continuous power; and	
5.22.1.2 The means for stopping and locking the rotor(s) shall be operated as specified in the EPU operating instructions while being subjected to the maximum torque that could result from continued flight in this condition; and	
5.22.1.3 Following rotor locking, the rotor(s) shall be held stationary under these conditions for a time interval sufficient to establish reliable performance of the locking mechanism for each of the repeated operations described at the beginning of this section. The proposed time interval shall be justified.	
5.23 Teardown Inspection:	Listed for reference only
5.22.1 After completing the endurance test, the vibration test, the overtorque test, and the overtemperature test:	
5.23.1.1 Each EPU shall be completely disassembled;	
5.23.1.2 Each EPU component having an adjustment setting and a functioning characteristic that can be established independent of installation on or in the EPU shall retain each setting and functioning characteristic within the limits that were established and recorded at the beginning of the test; and	
5.23.1.3 Each EPU component shall conform to the type design and be eligible for incorporation into an EPU for continued operation, in accordance with information submitted in compliance with the Instructions for Continued Airworthiness.	Listed for reference only
5.23.1.4 If the EPU is assembled in a manner that it cannot be disassembled without destructive inspection, such as one that is epoxied together, and it will be nonworkable after teardown, alternative inspection can be proposed. There may be nondestructive tests for electrical systems. However, these alternative methods shall capture the critical aspects intended for the inspection. Pre-measurements at build shall be referenced at teardown.	
5.23.1.5 If a teardown is not performed, then the life limit of the EPU will be established by the length of the endurance test performed.	
5.24 Containment:	Listed for reference only
5.24.1 Rotating Part Containment—The design of the cases that surround rotating components shall provide for the containment of damage from failure of the rotating components. Fragments resulting from rotating component failure that escape containment shall have their energy levels and trajectories defined by test or analysis.	
5.25 EPU-Variable Pitch Propeller or Fan Systems Tests:	Listed for reference only
5.25.1 These are functional tests of the EPU operation, not an endurance test, to be conducted as applicable for a variable pitch design. If the EPU is designed to operate with a propeller or fan that is not part of the EPU type design, then the following tests shall be conducted with a representative propeller or fan installed by either including the tests in the endurance run or otherwise performing them in a manner acceptable to the CAA:	
5.25.1.1 Feathering Operation—The propeller should be feathered a sufficient number of times to establish reliable operation of the EPU in the propeller feathering dynamic operation. In absence of other justified number of sufficient test cycles, a minimum of 25 cycles may be used.	
5.25.1.2 Negative torque and thrust system operation: The negative torque and thrust system should be tested from rated maximum continuous power or from the most critical condition a sufficient number of times to establish reliable operation of the EPU in the negative torque and thrust system dynamic operation. In absence of other justified number of sufficient test cycles, a minimum of 25 cycles may be used. It should be shown by test that the negative torque effect on the EPU during windmill operation will not adversely affect bearing lubrication system.	

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5.25.1.3 Reverse Thrust Operation—The reverse thrust operation should be tested from the least power position to full reverse for a number of cycles sufficient to establish the reliability of the EPU in the dynamic operation of the reverse thrust system. In absence of other justified number of sufficient test cycles, a minimum of 175 cycles may be used. The reverse thrust operation at rated maximum continuous power from full forward to full reverse thrust for a number of cycles sufficient to establish the reliability of the reverse thrust system should also be tested. In absence of other justified number of sufficient test cycles, a minimum of 25 cycles may be used. At the end of each cycle, the propeller or fan shall be operated in reverse pitch for a time interval sufficient to establish the reliability of the reverse pitch mechanism and shall occur at the maximum rotational speed and power specified for reverse pitch operation. In absence of other justified time interval, a minimum of 30 s may be used.	Listed for reference only
5.26 Tests for Fixed-Pitch Propellers or Fans when Included in the EPU Type Certificate:	This section to be covered in 14 CFR 35.
5.26.1 The fixed-pitch propeller or fan which certification with the EPU is sought should meet all the applicable paragraphs of this specification and should be installed during all applicable EPU tests of this specification.	
5.26.2 The vibratory stress for the fixed-pitch propeller or fan should be shown to be acceptable throughout the declared flight envelope of the intended aircraft installation.	

3.9 Subpart G, Special Requirements: Turbine Aircraft Engines

In light of magniX special condition 1, and in combination with earlier findings presented by HS Advance Concepts personnel, 14 CFR 33 Subpart G will not be addressed in this document.

3.10 Appendix A to Part 33, Instructions for Continued Airworthiness

The magniX special condition 1 states that unless otherwise noted in these special conditions, the design must comply with the airworthiness standards for aircraft engines set forth in 14 CFR part 33, except those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines. Therefore, Appendix A is applicable to the X-57.

3.10.1 Unique Aspects of X-57 to This Subpart

The approach to the Instructions for Continued Airworthiness (ICA) is as shown.

3.10.2 Certification Basis

Appendix A to Part 33—Instructions for Continued Airworthiness	Notes
a33.1 general	*Modified*
(a) This appendix specifies requirements for the preparation of Instructions for Continued Airworthiness as required by §33.4.	
(b) The Instructions for Continued Airworthiness for each engine must include the Instructions for Continued Airworthiness for all engine parts. If Instructions for Continued Airworthiness are not supplied by the engine part manufacturer for an engine part, the Instructions for Continued Airworthiness for the engine must include the information essential to the continued airworthiness of the engine.	
(c) The applicant must submit to the FAA a program to show how changes to the Instructions for Continued Airworthiness made by the applicant or by the manufacturers of engine parts will be distributed.	
a33.2 format	
(a) The Instructions for Continued Airworthiness must be in the form of a manual or manuals as appropriate for the quantity of data to be provided.	
(b) The format of the manual or manuals must provide for a practical arrangement.	
a33.3 content	

Appendix A to Part 33—Instructions for Continued Airworthiness	Notes
The contents of the manual or manuals must be prepared in the English language. The Instructions for Continued Airworthiness must contain the following manuals or sections, as appropriate, and information:	
(a) Engine Maintenance Manual or Section. (1) Introduction information that includes an explanation of the engine's features and data to the extent necessary for maintenance or preventive maintenance.	
(2) A detailed description of the engine and its components, systems, and installations.	
(3) Installation instructions, including proper procedures for uncrating, deinhibiting, acceptance checking, lifting, and attaching accessories, with any necessary checks.	
(4) Basic control and operating information describing how the engine components, systems, and installations operate, and information describing the methods of starting, running, testing, and stopping the engine and its parts including any special procedures and limitations that apply.	
(5) Servicing information that covers details regarding servicing points, capacities of tanks, reservoirs, types of fluids to be used, pressures applicable to the various systems, locations of lubrication points, lubricants to be used, and equipment required for servicing.	
(6) Scheduling information for each part of the engine that provides the recommended periods at which it should be cleaned, inspected, adjusted, tested, and lubricated, and the degree of inspection the applicable wear tolerances, and work recommended at these periods. However, the applicant may refer to an accessory, instrument, or equipment manufacturer as the source of this information if the applicant shows that the item has an exceptionally high degree of complexity requiring specialized maintenance techniques, test equipment, or expertise. The recommended overhaul periods and necessary cross references to the Airworthiness Limitations section of the manual must also be included. In addition, the applicant must include an inspection program that includes the frequency and extent of the inspections necessary to provide for the continued airworthiness of the engine.	*Modified*
(7) Troubleshooting information describing probable malfunctions, how to recognize those malfunctions, and the remedial action for those malfunctions.	
(8) Information describing the order and method of removing the engine and its parts and replacing parts, with any necessary precautions to be taken. Instructions for proper ground handling, crating, and shipping must also be included.	
(9) A list of the tools and equipment necessary for maintenance and directions as to their method of use.	
(b) engine Overhaul Manual or Section. (1) Disassembly information including the order and method of disassembly for overhaul.	
(2) Cleaning and inspection instructions that cover the materials and apparatus to be used and methods and precautions to be taken during overhaul. Methods of overhaul inspection must also be included.	
(3) Details of all fits and clearances relevant to overhaul.	
(4) Details of repair methods for worn or otherwise substandard parts and components along with the information necessary to determine when replacement is necessary.	
(5) The order and method of assembly at overhaul.	
(6) Instructions for testing after overhaul.	
(7) Instructions for storage preparation, including any storage limits.	
(8) A list of tools needed for overhaul.	
(c) ETOPS Requirements. For an applicant seeking eligibility for an engine to be installed on an airplane approved for ETOPS, the Instructions for Continued Airworthiness must include procedures for engine condition monitoring. The engine condition monitoring procedures must be able to determine prior to flight, whether an engine is capable of providing, within approved engine operating limits, maximum continuous power or thrust, bleed air, and power extraction required for a relevant engine inoperative diversion. For an engine to be installed on a two-engine airplane approved for ETOPS, the engine condition monitoring procedures must be validated before ETOPS eligibility is granted.	
A33.4 airworthiness limitations section	
The Instructions for Continued Airworthiness must contain a section titled Airworthiness Limitations that is segregated and clearly distinguishable from the rest of the manual.	
(a) For all engines:	

Appendix A to Part 33—Instructions for Continued Airworthiness	**Notes**
(1) The Airworthiness Limitations section must set forth each mandatory replacement time, inspection interval, and related procedure required for type certification. If the Instructions for Continued Airworthiness consist of multiple documents, the section required under this paragraph must be included in the principal manual.	*Modified*
(2) This section must contain a legible statement in a prominent location that reads: "The Airworthiness Limitations section is FAA approved and specifies maintenance required under §§43.16 and 91.403 of Title 14 of the Code of Federal Regulations unless an alternative program has been FAA approved."	
(b) For rotorcraft engines having 30-second OEI and 2-minute OEI ratings:	
(1) The Airworthiness Limitations section must also prescribe the mandatory post-flight inspections and maintenance actions associated with any use of either 30-second OEI or 2-minute OEI ratings.	
(2) The applicant must validate the adequacy of the inspections and maintenance actions required under paragraph (b)(1) of this section A33.4.	
(3) The applicant must establish an in-service engine evaluation program to ensure the continued adequacy of the instructions for mandatory post-flight inspections and maintenance actions prescribed under paragraph (b)(1) of this section A33.4 and of the data for §33.5(b)(4) pertaining to power availability. The program must include service engine tests or equivalent service engine test experience on engines of similar design and evaluations of service usage of the 30-second OEI or 2-minute OEI ratings. [ref: Amendment 33-9, 45 FR 60181, Sept. 11, 1980, as amended by Amendment 33-13, 54 FR 34330, Aug. 18, 1989; Amendment 33-21, 72 FR 1878, Jan. 16, 2007; Amendment 33-25, 73 FR 48124, Aug. 18, 2008]	

3.11 Appendix B to Part 33, Certification Standard Atmospheric Concentrations of Rain and Hail

magniX special condition 1 states that unless otherwise noted in these special conditions, the design must comply with the airworthiness standards for aircraft engines set forth in 14 CFR part 33, except those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines. However, as Appendix B specifically applies to gas turbine engines, it is not applicable to the X-57.

3.12 Appendix C to Part 33, [Reserved]

Appendix C to Part 33 [Reserved]	*N/A*

3.13 Appendix D to Part 33, Mixed Phase and Ice Crystal Icing Envelope (Deep Convective Clouds)

magniX special condition 1 states that unless otherwise noted in these special conditions, the design must comply with the airworthiness standards for aircraft engines set forth in 14 CFR part 33, except those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines. However, as Appendix D specifically applies to gas turbine engines, it is not applicable to the X-57.

4 Propellers

This section is organized by its Subparts to 14 CFR 35, including Subpart A, General, Subpart B, Design and Construction, and Subpart C, Tests and Inspections. A discussion about Appendix A to Part 35, Instructions for Continued Airworthiness is also summarized.

For each certification basis in each of the Subparts, an assessment was made and color-coded as to NASA's X-57 flight demonstrator to meet:

- Green: The means of compliance and methods of compliance associated with existing Standard Specifications and Standard Practices.
- Yellow: If such standards do not exist or are not appropriate, an equivalent means and-or methods of compliance from appropriate FAA Advisory Circulars and other sources are suggested.
- Red: If no appropriate certification rule, means of compliance, and-or method of compliance exists, highlight this omission and provide recommendations.
- Grey: If the certification basis is not applicable to the X-57.

A summary of the distribution of the assessments of the certification basis by Subpart for Normal Category Aircraft is shown below.

	GREEN	YELLOW	RED	GREY
SUBPART A—GENERAL	50%	50%	0%	0%
SUBPART B—DESIGN AND CONSTRUCTION	87%	13%	0%	0%
SUBPART C—TESTS AND INSPECTIONS	81%	9%	0%	9%
APPENDIX A TO PART 35—INSTRUCTIONS FOR CONTINUED AIRWORTHINESS	100%	0%	0%	0%

In general, there are two applications of propeller requirements for the X-57. The first is the more traditional propeller used for all phases of flight and is referred to as the "Traction Propeller." There are two traction propellers affixed to the traction motors on the wingtips of the X-57. A traditional application of FAR 35 is expected.

The second propeller requirement for the X-57 is for the "high-lift propellers" affixed to the high-lift motors. These propellers are only used during takeoff and approach to landing and are stowed when not in use. These propellers are smaller in diameter than traditional aircraft propellers and foldable so that they may be stowed when not used. The development of standards for these propellers will rest on the technology and knowledge transfer from the X-57. An evaluation showed that modification associated with stowing part 35 is applicable.

Part 35 Amendment 10 was written to encompass a wide variety of propeller configurations: fixed pitch, ground adjustable pitch, variable pitch, etc. Part 35 did not address potential hazardous effects associated with stowable propellers. Therefore, additional requirements have been added.

The propeller requirements have been modified for the X-57 airplane certificated under 21.17 for propellers approved under the airplane type certificate. The base requirements for the propeller are FAR part 35 Amendment 10. The part 35 requirements are modified for propellers approved under the airplane type certificate. A propeller with a propeller type certificate that does not have stowable blades may also be used as specified in §23.2400 Powerplant installation.

4.1 Subpart A, General

4.1.1 Unique Aspects of X-57 to This Subpart

The approach for Subpart A is to modify part 35 for the traction propellers and high-lift propellers and their applicability to the X-57.

4.1.2 Certification Basis

Subpart A—General	Notes
§35.1 Applicability.	Modified for the propeller approved under the airplane type certificate.
(a) This part prescribes airworthiness standards for the issue of type certificates and changes to those certificates, for propellers.	
(b) Each person who applies under part 21 for such a certificate or change must show compliance with the applicable requirements of this part.	
(c) An applicant is eligible for a propeller type certificate and changes to those certificates after demonstrating compliance with subparts A, B, and C of this part. However, the propeller may not be installed on an airplane unless the applicant has shown compliance with either §23.2400(c) or §25.907 of this chapter, as applicable, or compliance is not required for installation on that airplane.	
(d) For the purposes of this part, the propeller consists of those components listed in the propeller type design, and the propeller system consists of the propeller and all the components necessary for its functioning, but not necessarily included in the propeller type design. [ref: Amendment 35-3, 41 FR 55475, Dec. 20, 1976, as amended by Amendment 35-8, 73 FR 63346, Oct. 24, 2008; Doc. FAA-2015-1621, Amendment 35-10, 81 FR 96700, Dec. 30, 2016]	
§35.2 Propeller configuration.	Modified for the propeller approved under the airplane type certificate.
The applicant must provide 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 under §21.31 of this chapter. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]	
§35.3 Instructions for propeller installation and operation.	Unchanged
The applicant must provide instructions that are approved by the Administrator. Those approved instructions must contain:	
(a) Instructions for installing the propeller, which:	
(1) Include a description of the operational modes of the propeller control system and functional interface of the control system with the airplane and engine systems;	
(2) Specify the physical and functional interfaces with the airplane, airplane equipment and engine;	
(3) Define the limiting conditions on the interfaces from paragraph (a)(2) of this section;	
(4) List the limitations established under §35.5;	
(5) Define the hydraulic fluids approved for use with the propeller, including grade and specification, related operating pressure, and filtration levels; and	
(6) State the assumptions made to comply with the requirements of this part.	
(b) Instructions for operating the propeller which must specify all procedures necessary for operating the propeller within the limitations of the propeller type design. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]	
§35.4 Instructions for Continued Airworthiness.	Unchanged
The applicant must prepare Instructions for Continued Airworthiness in accordance with appendix A to this part that are acceptable to the Administrator. The instructions may be incomplete at type certification if a program exists to ensure their completion prior to delivery of the first aircraft with the propeller installed, or upon issuance of a standard certificate of airworthiness for an aircraft with the propeller installed, whichever occurs later. [ref: Amdt. 35-5, 45 FR 60181, Sept. 11, 1980]	
§35.5 Propeller ratings and operating limitations.	Modified, the propeller is approved under the airplane type certificate
(a) Propeller ratings and operating limitations must:	
(1) Be established by the applicant and approved by the Administrator.	
(2) Be included directly or by reference in the propeller type certificate data sheet, as specified in §21.41 of this chapter.	

Subpart A—General	Notes
(3) Be based on the operating conditions demonstrated during the tests required by this part as well as any other information the Administrator requires as necessary for the safe operation of the propeller.	The traditional power, rotational speed, takeoff, etc., may not be applicable for the propeller. Requirements associated with traditional rating are deleted.
(b) Propeller ratings and operating limitations must be established for the following, as applicable:	
(1) Power and rotational speed:	
(i) For takeoff.	
(ii) For maximum continuous.	
(iii) If requested by the applicant, other ratings may also be established.	
(2) Overspeed and overtorque limits. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]	
§35.7 Features and characteristics.	Unchanged
(a) 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.	
(b) If a failure occurs during a certification test, the applicant must determine the cause and assess the effect on the airworthiness of the propeller. The applicant must make changes to the design and conduct additional tests that the Administrator finds necessary to establish the airworthiness of the propeller. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]	

4.1.3 Subpart A, Requirement Modifications

§35.1 Applicability.	
(a) This part prescribes airworthiness standards for *propellers certificated with the airplane.* ~~*the issue of type certificates and changes to those certificates, for propellers.*~~	Modified for the propeller approved under the airplane type certificate.
(b) Each person who applies under part 21 for such a certificate or change must show compliance with the applicable requirements of this part.	No change
~~*(c) An applicant is eligible for a propeller type certificate and changes to those certificates after demonstrating compliance with subparts A, B, and C of this part. However, the propeller may not be installed on an airplane unless the applicant has shown compliance with either §23.2400(c) or §25.907 of this chapter, as applicable, or compliance is not required for installation on that airplane.*~~	Delete, the propeller is approved under the airplane type certificate.
(d) For the purposes of this part, the propeller consists of those components listed in the propeller type design, and the propeller system consists of the propeller and all the components necessary for its functioning~~*, but not necessarily included in the propeller type design*~~.	Modified, the propeller is approved under the airplane type certificate.
§35.2 Propeller configuration.	
The applicant must provide 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 under §*21.17*~~*31*~~ of this chapter.	Modified, the propeller is approved under the airplane type certificate.
§35.5 Propeller ratings and operating limitations.	
(a) Propeller ratings and operating limitations must:	No change
(1) Be established by the applicant and approved by the Administrator.	No change
(2) Be included directly or by reference in the ~~propeller type certificate data sheet~~ *airplane type certificate data sheet*, as specified in §21.41 of this chapter.	Modified, the propeller is approved under the airplane type certificate.
(b) Propeller ratings and operating limitations must be established for the *propeller* ~~*following*~~ *and approved by the Administrator*, as applicable:	The traditional power, rotational speed, takeoff, etc., may not be applicable for the propeller.
~~*(1) Power and rotational speed:*~~	Delete
~~*(i) For takeoff.*~~	Delete
~~*(ii) For maximum continuous.*~~	Delete
~~*(iii) If requested by the applicant, other ratings may also be established.*~~	Delete
~~*(2) Overspeed and overtorque limits.*~~	Delete

4.2 Subpart B, Design and Construction

4.2.1 Unique Aspects of X-57 to This Subpart

The approach for Subpart B is to modify part 35 for the traction propellers and high-lift propellers and their applicability to the X-57. New requirements were added for stowable propellers. 35.15 (g)(1)(v) and *35.TDB* Stowable Propellers.

4.2.2 Certification Basis

Subpart B—Design and Construction	**Notes**
§35.11 [Reserved]	
§35.13 [Reserved]	
§35.15 Safety analysis.	(a)(1)(i) Modified, the propeller is approved under the airplane type certificate. (g)(1)(v) New requirement for stowable propellers.
(a)(1) The applicant must analyze the propeller system to assess the likely consequences of all failures that can reasonably be expected to occur. This analysis will take into account, if applicable:	
(i) The propeller system in a typical installation. When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.	
(ii) Consequential secondary failures and dormant failures.	
(iii) Multiple failures referred to in paragraph (d) of this section, or that result in the hazardous propeller effects defined in paragraph (g)(1) of this section.	
(2) The applicant must summarize those failures that could result in major propeller effects or hazardous propeller effects defined in paragraph (g) of this section, and estimate the probability of occurrence of those effects.	
(3) The applicant must show that hazardous propeller effects are not predicted to occur at a rate in excess of that defined as extremely remote (probability of 10−7 or less per propeller flight hour). Since the estimated probability for individual failures may be insufficiently precise to enable the applicant to assess the total rate for hazardous propeller effects, compliance may be shown by demonstrating that the probability of a hazardous propeller effect arising from an individual failure can be predicted to be not greater than 10−8 per propeller flight hour. In dealing with probabilities of this low order of magnitude, absolute proof is not possible and reliance must be placed on engineering judgment and previous experience combined with sound design and test philosophies.	
(b) If significant doubt exists as to the effects of failures or likely combination of failures, the Administrator may require assumptions used in the analysis to be verified by test.	
(c) The primary failures of certain single propeller elements (for example, blades) cannot be sensibly estimated in numerical terms. If the failure of such elements is likely to result in hazardous propeller effects, those elements must be identified as propeller critical parts. For propeller critical parts, applicants must meet the prescribed integrity specifications of §35.16. These instances must be stated in the safety analysis.	
(d) If reliance is placed on a safety system to prevent a failure progressing to hazardous propeller effects, the possibility of a safety system failure in combination with a basic propeller failure must be included in the analysis. Such a safety system may include safety devices, instrumentation, early warning devices, maintenance checks, and other similar equipment or procedures. If items of the safety system are outside the control of the propeller manufacturer, the assumptions of the safety analysis with respect to the reliability of these parts must be clearly stated in the analysis and identified in the propeller installation and operation instructions required under §35.3.	
(e) If the safety analysis depends on one or more of the following items, those items must be identified in the analysis and appropriately substantiated.	
(1) Maintenance actions being carried out at stated intervals. This includes verifying that items that could fail in a latent manner are functioning properly. When necessary to prevent hazardous propeller effects, these maintenance actions and intervals must be published in the instructions for continued airworthiness required under §35.4. Additionally, if errors in maintenance of the propeller system could lead to hazardous propeller effects, the appropriate maintenance procedures must be included in the relevant propeller manuals.	

Subpart B—Design and Construction	Notes
(2) Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details of this satisfactory functioning must be published in the appropriate manual.	
(3) The provision of specific instrumentation not otherwise required. Such instrumentation must be published in the appropriate documentation.	
(4) A fatigue assessment.	
(f) If applicable, the safety analysis must include, but not be limited to, assessment of indicating equipment, manual and automatic controls, governors and propeller control systems, synchrophasers, synchronizers, and propeller thrust reversal systems.	
(g) Unless otherwise approved by the Administrator and stated in the safety analysis, the following failure definitions apply to compliance with this part.	
(1) The following are regarded as hazardous propeller effects:	
(i) The development of excessive drag.	
(ii) A significant thrust in the opposite direction to that commanded by the pilot.	
(iii) The release of the propeller or any major portion of the propeller.	
(iv) A failure that results in excessive unbalance.	
(2) The following are regarded as major propeller effects for variable pitch propellers:	
(i) An inability to feather the propeller for feathering propellers.	
(ii) An inability to change propeller pitch when commanded.	
(iii) A significant uncommanded change in pitch.	
(iv) A significant uncontrollable torque or speed fluctuation. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008, as amended by Amendment 35-9, 78 FR 4041, Jan. 18, 2013; Amendment 35-9A, 78 FR 45052, July 26, 2013]	
§35.16 Propeller critical parts.	Unchanged
The integrity of each propeller critical part identified by the safety analysis required by §35.15 must be established by:	
(a) A defined engineering process for ensuring the integrity of the propeller critical part throughout its service life,	
(b) A defined manufacturing process that identifies the requirements to consistently produce the propeller critical part as required by the engineering process, and	
(c) A defined service management process that identifies the continued airworthiness requirements of the propeller critical part as required by the engineering process. [ref: Amendment 35-9, 78 FR 4042, Jan. 18, 2013]	
§35.17 Materials and manufacturing methods.	Unchanged
(a) The suitability and durability of materials used in the propeller must:	
(1) Be established on the basis of experience, tests, or both.	
(2) Account for environmental conditions expected in service.	
(b) All materials and manufacturing methods must conform to specifications acceptable to the Administrator.	
(c) The design values of properties of materials must be suitably related to the most adverse properties stated in the material specification for applicable conditions expected in service. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]	
§35.19 Durability.	Unchanged
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.	Unchanged
(a) No single failure or malfunction in the propeller system will result in unintended travel of the propeller blades to a position below the in-flight low-pitch position. The extent of any intended travel below the in-flight low-pitch position must be documented by the applicant in the appropriate manuals. Failure of structural elements need not be considered if the occurrence of such a failure is shown to be extremely remote under §35.15.	
(b) For propellers incorporating a method to select blade pitch below the in-flight low pitch position, provisions must be made to sense and indicate to the flight crew that the propeller blades are below that position by an amount defined in the installation manual. The method for sensing and indicating the propeller blade pitch position must be such that its failure does not affect the control of the propeller. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]	
§35.22 Feathering propellers.	Unchanged

Subpart B—Design and Construction	**Notes**
(a) Feathering propellers are intended to feather from all flight conditions, taking into account expected wear and leakage. Any feathering and unfeathering limitations must be documented in the appropriate manuals.	
(b) Propeller pitch control systems that use engine oil to feather must incorporate a method to allow the propeller to feather if the engine oil system fails.	
(c) Feathering propellers must be designed to be capable of unfeathering after the propeller system has stabilized to the minimum declared outside air temperature. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]	
§35.23 Propeller control system.	Unchanged
The requirements of this section apply to any system or component that controls, limits or monitors propeller functions.	
(a) The propeller control system must be designed, constructed and validated to show that:	
(1) The propeller control system, operating in normal and alternative operating modes and in transition between operating modes, performs the functions defined by the applicant throughout the declared operating conditions and flight envelope.	
(2) The propeller control system functionality is not adversely affected by the declared environmental conditions, including temperature, electromagnetic interference (EMI), high intensity radiated fields (HIRF) and lightning. The environmental limits to which the system has been satisfactorily validated must be documented in the appropriate propeller manuals.	
(3) A method is provided to indicate that an operating mode change has occurred if flight crew action is required. In such an event, operating instructions must be provided in the appropriate manuals.	
(b) The propeller control system must be designed and constructed so that, in addition to compliance with §35.15:	
(1) No single failure or malfunction of electrical or electronic components in the control system results in a hazardous propeller effect.	
(2) Failures or malfunctions directly affecting the propeller control system in a typical airplane, such as structural failures of attachments to the control, fire, or overheat, do not lead to a hazardous propeller effect.	
(3) The loss of normal propeller pitch control does not cause a hazardous propeller effect under the intended operating conditions.	
(4) The failure or corruption of data or signals shared across propellers does not cause a hazardous propeller effect.	
(c) Electronic propeller control system imbedded software must be designed and implemented by a method approved by the Administrator that is consistent with the criticality of the performed functions and that minimizes the existence of software errors.	
(d) The propeller control system must be designed and constructed so that the failure or corruption of airplane-supplied data does not result in hazardous propeller effects.	
(e) The propeller control system must be designed and constructed so that the loss, interruption or abnormal characteristic of airplane-supplied electrical power does not result in hazardous propeller effects. The power quality requirements must be described in the appropriate manuals. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]	
§35.24 Strength.	Unchanged
The maximum stresses developed in the propeller may not exceed values acceptable to the Administrator considering the particular form of construction and the most severe operating conditions. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]	

4.2.3 Subpart B, Requirement Modifications and Additions

§35.15 Safety analysis.	
(a)(1) The applicant must analyze the propeller system to assess the likely consequences of all failures that can reasonably be expected to occur. This analysis will take into account, if applicable:	No change
(i) The propeller system ~~*in a typical installation*~~ *installed on the airplane.* When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.	Modified, the propeller is approved under the airplane type certificate.
(ii) Consequential secondary failures and dormant failures.	No change
(iii) Multiple failures referred to in paragraph (d) of this section, or that result in the hazardous propeller effects defined in paragraph (g)(1) of this section.	No change

(2) The applicant must summarize those failures that could result in major propeller effects or hazardous propeller effects defined in paragraph (g) of this section, and estimate the probability of occurrence of those effects.	No change
(3) The applicant must show that hazardous propeller effects are not predicted to occur at a rate in excess of that defined as extremely remote (probability of 10−7 or less per propeller flight hour). Since the estimated probability for individual failures may be insufficiently precise to enable the applicant to assess the total rate for hazardous propeller effects, compliance may be shown by demonstrating that the probability of a hazardous propeller effect arising from an individual failure can be predicted to be not greater than 10−8 per propeller flight hour. In dealing with probabilities of this low order of magnitude, absolute proof is not possible and reliance must be placed on engineering judgment and previous experience combined with sound design and test philosophies.	No change
(b) If significant doubt exists as to the effects of failures or likely combination of failures, the Administrator may require assumptions used in the analysis to be verified by test.	No change
(c) The primary failures of certain single propeller elements (for example, blades) cannot be sensibly estimated in numerical terms. If the failure of such elements is likely to result in hazardous propeller effects, those elements must be identified as propeller critical parts. For propeller critical parts, applicants must meet the prescribed integrity specifications of §35.16. These instances must be stated in the safety analysis.	No change
(d) If reliance is placed on a safety system to prevent a failure progressing to hazardous propeller effects, the possibility of a safety system failure in combination with a basic propeller failure must be included in the analysis. Such a safety system may include safety devices, instrumentation, early warning devices, maintenance checks, and other similar equipment or procedures. If items of the safety system are outside the control of the propeller manufacturer, the assumptions of the safety analysis with respect to the reliability of these parts must be clearly stated in the analysis and identified in the propeller installation and operation instructions required under §35.3.	No change
(e) If the safety analysis depends on one or more of the following items, those items must be identified in the analysis and appropriately substantiated.	No change
(1) Maintenance actions being carried out at stated intervals. This includes verifying that items that could fail in a latent manner are functioning properly. When necessary to prevent hazardous propeller effects, these maintenance actions and intervals must be published in the instructions for continued airworthiness required under §35.4. Additionally, if errors in maintenance of the propeller system could lead to hazardous propeller effects, the appropriate maintenance procedures must be included in the relevant propeller manuals.	No change
(2) Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details of this satisfactory functioning must be published in the appropriate manual.	No change
(3) The provision of specific instrumentation not otherwise required. Such instrumentation must be published in the appropriate documentation.	No change
(4) A fatigue assessment.	No change
(f) If applicable, the safety analysis must include, but not be limited to, assessment of indicating equipment, manual and automatic controls, governors and propeller control systems, synchrophasers, synchronizers, and propeller thrust reversal systems.	No change
(g) Unless otherwise approved by the Administrator and stated in the safety analysis, the following failure definitions apply to compliance with this part.	No change
(1) The following are regarded as hazardous propeller effects:	No change
(i) The development of excessive drag.	No change
(ii) A significant thrust in the opposite direction to that commanded by the pilot.	No change
(iii) The release of the propeller or any major portion of the propeller.	No change
(iv) A failure that results in excessive unbalance.	No change
(v) The inability to stow or unstow when required.	New requirement for stowable propellers.
(2) The following are regarded as major propeller effects for variable pitch propellers:	No change
(i) An inability to feather the propeller for feathering propellers.	No change
(ii) An inability to change propeller pitch when commanded.	No change
(iii) A significant uncommanded change in pitch.	No change
(iv) A significant uncontrollable torque or speed fluctuation.	No change
§35.TBD Stowable propellers.	

Stowable propellers are intended to stow and unstow as required by the phase of flight.	New requirement for stowable propellers. The ability to stow and unstow has been written for a propeller that is certified with the airplane and the phase of flight is known.

4.3 Subpart C, Tests and Inspections

4.3.1 Unique Aspects of X-57 to This Subpart

The approach for Subpart C is to modify part 35 for the traction propellers and high-lift propellers and their applicability to the X-57.

4.3.2 Certification Basis

Subpart C—Tests and Inspections	**Notes**
§35.31 [Reserved]	
§35.33 General.	Unchanged
(a) Each applicant must furnish test article(s) and suitable testing facilities, including equipment and competent personnel, and conduct the required tests in accordance with part 21 of this chapter.	
(b) All automatic controls and safety systems must be in operation unless it is accepted by the Administrator as impossible or not required because of the nature of the test. If needed for substantiation, the applicant may test a different propeller configuration if this does not constitute a less severe test.	
(c) Any systems or components that cannot be adequately substantiated by the applicant to the requirements of this part are required to undergo additional tests or analysis to demonstrate that the systems or components are able to perform their intended functions in all declared environmental and operating conditions. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]	
§35.34 Inspections, adjustments and repairs.	Unchanged
(a) Before and after conducting the tests prescribed in this part, the test article must be subjected to an inspection, and a record must be made of all the relevant parameters, calibrations and settings.	
(b) During all tests, only servicing and minor repairs are permitted. If major repairs or part replacement is required, the Administrator must approve the repair or part replacement prior to implementation and may require additional testing. Any unscheduled repair or action on the test article must be recorded and reported. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]	
§35.35 Centrifugal load tests.	Unchanged
The applicant must 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. This section does not apply to fixed-pitch wood or fixed-pitch metal propellers of conventional design.	
(a) The hub, blade retention system, and counterweights must be tested for a period of one hour to a load equivalent to twice the maximum centrifugal load to which the propeller would be subjected during operation at the maximum rated rotational speed.	
(b) Blade features associated with transitions to the retention system (for example, a composite blade bonded to a metallic retention) must be tested either during the test of paragraph (a) of this section or in a separate component test for a period of one hour to a load equivalent to twice the maximum centrifugal load to which the propeller would be subjected during operation at the maximum rated rotational speed.	
(c) Components used with or attached to the propeller (for example, spinners, de-icing equipment, and blade erosion shields) must be subjected to a load equivalent to 159 percent of the maximum centrifugal load to which the component would be subjected during operation at the maximum rated rotational speed. This must be performed by either:	
(1) Testing at the required load for a period of 30 minutes; or	

Subpart C—Tests and Inspections	Notes
(2) Analysis based on test. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]	
§35.36 Bird impact.	Unchanged
The applicant must 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. This section does not apply to fixed-pitch wood propellers of conventional design. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]	
§35.37 Fatigue limits and evaluation.	Modified, the propeller is approved under the airplane type certificate .
This section does not apply to fixed-pitch wood propellers of conventional design.	
(a) Fatigue limits must be established by tests, or analysis based on tests, for propeller:	
(1) Hubs.	
(2) Blades.	
(3) Blade retention components.	
(4) Components which are affected by fatigue loads and which are shown under §35.15 to have a fatigue failure mode leading to hazardous propeller effects.	
(b) The fatigue limits must take into account:	
(1) All known and reasonably foreseeable vibration and cyclic load patterns that are expected in service; and	
(2) Expected service deterioration, variations in material properties, manufacturing variations, and environmental effects.	
(c) A fatigue evaluation of the propeller must be conducted to show that hazardous propeller effects due to fatigue will be avoided throughout the intended operational life of the propeller on either:	
(1) The intended airplane by complying with §23.2400(c) or §25.907 of this chapter, as applicable; or	
(2) A typical airplane. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008, as amended by Doc. FAA-2015-1621, Amendment 35-10, 81 FR 96700, Dec. 30, 2016]	
§35.38 Lightning strike.	Not Applicable The X-57 is prohibited from flying in or around convective weather.
The applicant must 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. The limit to which the propeller has been qualified must be documented in the appropriate manuals. This section does not apply to fixed-pitch wood propellers of conventional design. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]	
§35.39 Endurance test.	Unchanged
Endurance tests on the propeller system must be made on a representative engine in accordance with paragraph (a) or (b) of this section, as applicable, without evidence of failure or malfunction.	
(a) Fixed-pitch and ground adjustable-pitch propellers must be subjected to one of the following tests:	
(1) A 50-hour flight test in level flight or in climb. The propeller must be operated at takeoff power and rated rotational speed during at least five hours of this flight test, and at not less than 90 percent of the rated rotational speed for the remainder of the 50 hours.	
(2) A 50-hour ground test at takeoff power and rated rotational speed.	
(b) Variable-pitch propellers must be subjected to one of the following tests:	
(1) A 110-hour endurance test that must include the following conditions:	
(i) Five hours at takeoff power and rotational speed and thirty 10-minute cycles composed of:	
(A) Acceleration from idle,	
(B) Five minutes at takeoff power and rotational speed,	
(C) Deceleration, and	
(D) Five minutes at idle.	
(ii) Fifty hours at maximum continuous power and rotational speed,	
(iii) Fifty hours, consisting of ten 5-hour cycles composed of:	
(A) Five accelerations and decelerations between idle and takeoff power and rotational speed,	
(B) Four and one half hours at approximately even incremental conditions from idle up to, but not including, maximum continuous power and rotational speed, and	
(C) Thirty minutes at idle.	
(2) The operation of the propeller throughout the engine endurance tests prescribed in part 33 of this chapter.	

Subpart C—Tests and Inspections	**Notes**
(c) An analysis based on tests of propellers of similar design may be used in place of the tests of paragraphs (a) and (b) of this section. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]	
§35.40 Functional test.	Unchanged
The 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. This test may be combined with the endurance test for accumulation of cycles.	
(a) Manually-controllable propellers. Five hundred representative flight cycles must be made across the range of pitch and rotational speed.	
(b) Governing propellers. Fifteen hundred complete cycles must be made across the range of pitch and rotational speed.	
(c) Feathering propellers. Fifty cycles of feather and unfeather operation must be made.	
(d) Reversible-pitch propellers. Two hundred complete cycles of control must be made from lowest normal pitch to maximum reverse pitch. During each cycle, the propeller must run for 30 seconds at the maximum power and rotational speed selected by the applicant for maximum reverse pitch.	
(e) An analysis based on tests of propellers of similar design may be used in place of the tests of this section. [ref: Amendment 35-8, 73 FR 63349, Oct. 24, 2008]	
§35.41 Overspeed and overtorque.	Unchanged
(a) When the applicant seeks approval of a transient maximum propeller overspeed, the applicant must demonstrate that the propeller is capable of further operation without maintenance action at the maximum propeller overspeed condition. This may be accomplished by:	
(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overspeed condition; or	
(2) Analysis based on test or service experience.	
(b) When the applicant seeks approval of a transient maximum propeller overtorque, the applicant must demonstrate that the propeller is capable of further operation without maintenance action at the maximum propeller overtorque condition. This may be accomplished by:	
(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overtorque condition; or	
(2) Analysis based on test or service experience. [ref: Amendment 35-8, 73 FR 63349, Oct. 24, 2008]	
§35.42 Components of the propeller control system.	Unchanged
The applicant must 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. [ref: Amendment 35-8, 73 FR 63349, Oct. 24, 2008]	
§35.43 Propeller hydraulic components.	Unchanged
Applicants must 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 by:	
(a) A proof pressure test to 1.5 times the maximum operating pressure for one minute without permanent deformation or leakage that would prevent performance of the intended function.	
(b) A burst pressure test to 2.0 times the maximum operating pressure for one minute without failure. Leakage is permitted and seals may be excluded from the test. [ref: Amendment 35-8, 73 FR 63349, Oct. 24, 2008]	
§§35.45-35.47 [Reserved]	

4.3.3 Subpart B, Requirement Modifications and Additions

§35.37 Fatigue limits and evaluation.	
This section does not apply to fixed-pitch wood propellers of conventional design.	No change
(a) Fatigue limits must be established by tests, or analysis based on tests, for propeller:	No change

(1) Hubs.	No change
(2) Blades.	No change
(3) Blade retention components.	No change
(4) Components which are affected by fatigue loads and which are shown under §35.15 to have a fatigue failure mode leading to hazardous propeller effects.	No change
(b) The fatigue limits must take into account:	No change
(1) All known and reasonably foreseeable vibration and cyclic load patterns that are expected in service; and	No change
(2) Expected service deterioration, variations in material properties, manufacturing variations, and environmental effects.	No change
(c) A fatigue evaluation of the propeller must be conducted to show that hazardous propeller effects due to fatigue will be avoided throughout the intended operational life of the propeller on either:	No change
(1) The intended airplane by complying with §23.2400(c) ~~*or §25.907*~~ of this chapter, as applicable~~*; or*~~	Modified, the propeller is approved under the airplane type certificate.
~~*(2) A typical airplane*~~	Modified, the propeller is approved under the airplane type certificate
~~§35.38 Lightning strike.~~	
~~The applicant must 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. The limit to which the propeller has been qualified must be documented in the appropriate manuals. This section does not apply to fixed-pitch wood propellers of conventional design.~~	Not Applicable The X-57 is prohibited from flying in or around convective weather.

4.4 Appendix A to Part 35, Instructions for Continued Airworthiness

4.4.1 Unique Aspects of X-57 to This Subpart

The approach for Instructions for Continued Airworthiness (ICA) is to modify part 35 for the traction propellers and high-lift propellers and their applicability to the X-57.

4.4.2 Certification Basis

Appendix A to Part 35—Instructions for Continued Airworthiness	**Notes**
a35.1 general	Unchanged
(a) This appendix specifies requirements for the preparation of Instructions for Continued Airworthiness as required by §35.4.	
(b) The Instructions for Continued Airworthiness for each propeller must include the Instructions for Continued Airworthiness for all propeller parts. If Instructions for Continued Airworthiness are not supplied by the propeller part manufacturer for a propeller part, the Instructions for Continued Airworthiness for the propeller must include the information essential to the continued airworthiness of the propeller.	
(c) The applicant must submit to the FAA a program to show how changes to the Instructions for Continued Airworthiness made by the applicant or by the manufacturers of propeller parts will be distributed.	
a35.2 format	Unchanged
(a) The Instructions for Continued Airworthiness must be in the form of a manual or manuals as appropriate for the quantity of data to be provided.	
(b) The format of the manual or manuals must provide for a practical arrangement.	
a35.3 content	Unchanged
The contents of the manual must be prepared in the English language. The Instructions for Continued Airworthiness must contain the following sections and information:	
(a) Propeller Maintenance Section. (1) Introduction information that includes an explanation of the propeller's features and data to the extent necessary for maintenance or preventive maintenance.	
(2) A detailed description of the propeller and its systems and installations.	
(3) Basic control and operation information describing how the propeller components and systems are controlled and how they operate, including any special procedures that apply.	

Appendix A to Part 35—Instructions for Continued Airworthiness	**Notes**
(4) Instructions for uncrating, acceptance checking, lifting, and installing the propeller.	
(5) Instructions for propeller operational checks.	
(6) Scheduling information for each part of the propeller that provides the recommended periods at which it should be cleaned, adjusted, and tested, the applicable wear tolerances, and the degree of work recommended at these periods. However, the applicant may refer to an accessory, instrument, or equipment manufacturer as the source of this information if it shows that the item has an exceptionally high degree of complexity requiring specialized maintenance techniques, test equipment, or expertise. The recommended overhaul periods and necessary cross-references to the Airworthiness Limitations section of the manual must also be included. In addition, the applicant must include an inspection program that includes the frequency and extent of the inspections necessary to provide for the continued airworthiness of the propeller.	
(7) Troubleshooting information describing probable malfunctions, how to recognize those malfunctions, and the remedial action for those malfunctions.	
(8) Information describing the order and method of removing and replacing propeller parts with any necessary precautions to be taken.	
(9) A list of the special tools needed for maintenance other than for overhauls.	
(b) Propeller Overhaul Section. (1) Disassembly information including the order and method of disassembly for overhaul.	
(2) Cleaning and inspection instructions that cover the materials and apparatus to be used and methods and precautions to be taken during overhaul. Methods of overhaul inspection must also be included.	
(3) Details of all fits and clearances relevant to overhaul.	
(4) Details of repair methods for worn or otherwise substandard parts and components along with information necessary to determine when replacement is necessary.	
(5) The order and method of assembly at overhaul.	
(6) Instructions for testing after overhaul.	
(7) Instructions for storage preparation including any storage limits.	
(8) A list of tools needed for overhaul.	
a35.4 airworthiness limitations section	
The Instructions for Continued Airworthiness must contain a section titled Airworthiness Limitations that is segregated and clearly distinguishable from the rest of the document. This section must set forth each mandatory replacement time, inspection interval, and related procedure required for type certification. This section must contain a legible statement in a prominent location that reads: "The Airworthiness Limitations section is FAA approved and specifies maintenance required under §§43.16 and 91.403 of the Federal Aviation Regulations unless an alternative program has been FAA approved." [ref: Amendment 35-5, 45 FR 60182, Sept. 11, 1980, as amended by Amendment 35-6, 54 FR 34330, Aug. 18, 1989]	

5 Summary

This Airworthiness Validation Plan describes the portions of 14 CFR Parts 23, 33, and 35 to the X-57. Many of the regulations and means of compliance can be attributed directly to the X-57, and some require tailored edits of the Regulations and their Means of Compliance (MoC) to apply to the X-57. Some require the development of MoC specifically for the X-57, reflecting the unique technologies being demonstrated by the X-57.

In particular, the benefits of the DEP system are spawning the development of standards that support its technology opportunity with the necessary means to comply with its safe design and operation. Currently, there are no standards for DEP, and therefore the work of the ASTM F44.40 Powerplant Subcommittee has established a working group to assess the effect of DEP on two EPU standards F3316 and F3239.

The EPUs that are part of the X-57 are well-positioned to inform the efforts in ASTM F44.40 on F3316 and F3239 and the seminal work in ASTM F39.05 on F3338.

In November 2020, the FAA issued the first set of special conditions for a 375 and 750 SHP EPU in the certification process by magniX. Given that both electric motors are designed to accept propellers and rely on 2×3-phase inverter architecture for redundancy, this special condition applies to the X-57 in most respects.

The new and novel features of the magniX EPUs that led to the decision to produce special conditions are best explained in the text published in the Federal Register[16].

Given the performance-based tone of the magniX special conditions, the F3338 specification becomes highly complementary to the special conditions, which is an objective many, both in industry and the various certification authorities, have sought to accomplish.

One fundamental assumption made in both the magniX special conditions and F3338 is the consideration of the electric motor and the motor controller as an inseparable pairing. As noted in F3338-20, the motor inverter and controller are typically physically integrated into a single package. Therefore, the term controller refers to either or both in this text.

In general, the application of standards based on the ASTM Standard ASTM F3338, “Design of Electric Propulsion Units for General Aviation Aircraft,” aligned with the magniX special conditions and applied to the X-57.

Electric storage systems are a gap in the current standards, and some insights from the regulations on fuel storage and fuel systems can be used as metaphors for ESS, but that gap is profound in the current regulations. The work that ASTM F39.05 is applying to ESS in the form of guidelines is evolving. Currently, the work that the RTCA did is considered the only acceptable MoC, despite its origins in Part 25 applications of Equipment.

Beyond these general commentaries, this report has identified “Key Challenges” based on the in-depth review of the regulations and MoC in sections 2 through 4, addressing 14 CFR Parts 23, 33, and 35.

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[16] Federal Register, Docket ID FAA-2020-0894, *magniX USA, Inc., magni250 and magni500 Model Engines,* Notice of Proposed Special Conditions, Published November 19, 2020 with comments closing on December 21, 2020. See https://www.federalregister.gov/documents/2020/11/19/2020-23434/special-conditions-magnix-usa-inc-magni250-and-magni500-model-engines

5.1 Key Challenges

This section summarizes the key challenges where current regulations-requirements and means of compliance do not currently exist in sufficient detail that could be generated from the results of the X-57. These key challenges are characterized as an FAA Issue Paper, as described in the FAA AC 20-166A, "Issue Paper Process" using Appendix A, "Issue Paper Format." The intent is to quote a portion of the AC 20-166A to "…form a valuable reference for future type certification programs and for development of regulatory changes. By describing significant or precedent-setting technical decisions and the rationales employed, they are ideal source documents."

For this report, only the "Subject," "Statement of Issue," and "Background" are shown. Other aspects of the Issue Paper Format may be incorporated in the future as necessary.

Three areas described in the following highlight critical challenges. They are in Part 23, Subpart B, Flight, Part 23, Subpart C, Structures, and Part 33, Aircraft Engines. These key challenges are unique to the design and intended operation of the X-57 in its Mod IV configuration.

5.1.1 Part 23, Subpart B, Flight

SUBJECT: X-57 stall speed (VSO, VS1) and minimum control speed (VMC) development for field performance testing and data development. See also Appendix D, X-57 Configurations for Airworthiness Certification Airspeed Development.

STATEMENT OF ISSUE: ASTM F3179/F3179M paragraphs 5, 6, 7, 13, 15, 16, 18 describe required testing for field performance and climb data development used to sow compliance to 14CFR Part 23 [23-64]. A prerequisite for field performance and climb speed development is completion of stall speed and minimum control speed development. ASTM F317/F3179M use these speeds as a basis for defining minimum takeoff and landing speeds, along with climb speeds. Additionally, climb speed/data development requires all-engines operating (AEO) and one engine inoperative (OEI) climb data in order to show compliance to 14 CFR Part 23 [23-64].

BACKGROUND: Part of stall speed/VMC development is defining the power setting and configuration for each required flight condition for which compliance must be shown. Given the X-57 unique design, power settings and engine/airframe configurations must be well-understood and agreed upon by the certifying authority. For the X-57, state of high-lift propulsion (HLP) system, and cruise motor (CM) system in addition to gear/flap positions for each phase of flight must be defined. Below is notional configuration matrix that would be required for stall speed/VMC testing.

Phase of Flight	HLP	CM	Flaps	Gear	Note
Takeoff	X	X	TO	DN	Is HLP variable, or set for a single power/prop setting? CM at TOP? Are several flap settings proposed for takeoff?
Takeoff Climb	X	X	TO	UP	Is HLP variable, or set for a single power/prop setting? CM at MCP?
Cruise Climb		X	UP	UP	CM at MCP?
Cruise		X	UP	UP	Variable CM as required?
Descent		X	UP	UP	Variable CM as required?
Approach	X	X	APP	UP	When is HLP selected?
Landing (LND)	X	X	LAND	DN	When are LND flaps selected?
Balked Landing	X	X	LAND	UP	

In addition to understanding power/configurations for each phase of flight, the following parameters must be defined, understood and agreed upon with the certifying authority.

Parameter	HLP	CM	
Power-off for stall speed testing	X (Idle selectable?)	Idle	Is HLP power variable or one setting?
Power on for stall speed testing	X?	MCP unless excessive attitude is encountered	HLP both on and off? What setting if power is selectable?
OEI	Is partial power possible, or is HLP all or none? Do high lift propellers automatically feather upon failure?	One CM out? Propeller featherable manually or automatically? Which motor is the "critical motor"?	Rudder bias available?
AEO	X	X. Power setting for takeoff climb, cruise climb, balked landing climb TBD?	Flaps UP is stipulated here for OEI climb performance. There may be an implication for HLP as a high lift device or a propulsion system.

ASTM standard F3180/F3180M and 14CFR 23.2110 requires stall speed development for each operational configuration proposed. As such, the stall speed matrix can be sizable given the various configurations and power settings available for each operational phase of flight.

A fundamental question arises concerning the operating concept of the HLP. Is the HLP system considered a high lift device similar to slats, or a propulsive device that provides additional wing lift while also providing propulsive capability? Classification of the HLP system is key to treatment of the system for certification purposes.

5.1.2 Part 23, Subpart C, Structures

SUBJECT: Currently the X-57 experimental prototype wing drawings show a single spar which is quite efficient for the type of airfoil but not desirable for meeting the residual strength criteria of composite structure.

STATEMENT OF ISSUE: It is envisioned that Amendment 63 to FAR 23.573 will be the basis for FAA certification to Paragraph 23.2240 of FAR 23, amendment 64 (Structural Durability). Paragraph 23.573 (Amendment 63) has been REQUIRED for certification of composite structure and may be used for metallic structure.

> **FAR 23. 573 (1) (3) says "** *The structure must be shown by residual strength tests, or analysis supported by residual strength tests, to be able to withstand critical limit flight loads, considered as ultimate loads, with the extent of detectable damage consistent with the results of the damage tolerance evaluations."*

BACKGROUND: Single load path primary structure is riskier than multi-load path. Fundamentally, if anything goes wrong such as incorrect inspection, manufacturing flaw different from test article, actual operational spectrum on a given aircraft different from the test program, any operational scenario outside the scope of the damage tolerance substantiation program and a single load path structure fails the result is likely catastrophic.

While FAR 23.573 allows for certification of single load path structure, this approach can add significantly to the in-service inspection and maintenance workloads and cost because sub-paragraph (a) (4) states:

> "*The damage growth, between initial detectability and the value selected for residual strength demonstrations, factored to obtain inspection intervals, must allow development of an inspection program suitable for application by operation and maintenance personnel.*"

A multiple load path design can assure that the required level of residual strength (limit load capability) is retained in the event of complete failure of any one element. Such a design reduces the risk of a catastrophic event and also allows for a less-demanding inspection and maintenance program.

5.1.3 Part 33, Aircraft Engines

The following are examples where the performance-based requirements of the magniX special conditions are appropriate, but where the authors of this document found MoC shortfalls in ASTM F3338's prescriptive measures. Further, EPU technology introduces several significant technological shifts which result in even the historically relevant Advisory Circulars being somewhat obsolete.

5.1.3.1 **SUBJECT**: magniX Special Condition 4; Fire Protection

STATEMENT OF ISSUE: Proposed special condition no. 4 would require magniX to comply with 14 CFR 33.17, which sets requirements to protect the engine and certain parts and components of the airplane against fire, and which would otherwise be applicable only to reciprocating and turbine aircraft engines. Additionally, this proposed special condition would require magniX to ensure the high-voltage electrical wiring interconnect systems that connect the controller to the motor are protected against arc-faults. There are a wide variety of approaches to the fundamental architecture and distribution of EPU systems and components. As a result, the requirements to develop custom MoCs will be common.

BACKGROUND: Neither this special condition, AC 33.17-1A, nor ASTM F3338-20 Section 5.5 is a complete treatment of the compliance standards likely to be required for an EPU. Given the evolution in technology, individual MoCs will likely be required on a project by project basis until such time as more uniform EPU architecture patterns emerge.

5.1.3.2 **SUBJECT**: magniX Special Condition 22; Calibration Test

STATEMENT OF ISSUE: Both the Administrator and the Applicant would benefit from an MoC which provides both specificity and granularity to this block test.

BACKGROUND: Reference ASTM F3338-20 Section 5.21.7. In addition, the authors recommend the addition of the calibration baseline data defined in IEC 60349-4 Clauses 8.1, 8.2, 9.2.2. 9.2.3 and 10.2.

5.1.3.3 **SUBJECT**: magniX Special Condition 23; Endurance Test

STATEMENT OF ISSUE: Both the Administrator and the Applicant would benefit from an MoC which provides both specificity and granularity to this block test.

BACKGROUND: For the reasons laid out in Section 3.8.1 of this document, the authors encourage the continued use of the prescriptive guidance found in 14 CFR 33.87. Neither this special condition, nor ASTM F3338-20 Section 5.5 is a complete treatment of the compliance standards likely to be required for an EPU.

5.1.3.4 **SUBJECT**: magniX Special Condition 24; Temperature Limit

STATEMENT OF ISSUE: Operation at maximum permissible rating is necessary to ensure proper accounting for eddy current and windage thermal loads. We disagree with the disclaimers in the ASTM standard that the test temperatures "must not violate the physical limitation of the permanent magnet material (Curie-temperature) including sufficient safety margin." The purpose of this test is to establish that margin exists.

BACKGROUND: Reference a mark-up of 14 CFR 33.88 in Section 3.8.2 of this document as a potential MoC.

5.2 Opportunity for Model-Based Systems Engineering

The findings of this report accentuate the complexity involved with the specification and identification of appropriate means of compliance for a novel vehicle architecture. This report additionally highlights opportunities to leverage the relationships between the certification regulations and artifacts of the vehicle architecture in order to address critical gaps in the means of compliance. This approach can be envisioned more broadly as a comparative analysis of the underlying models of the certification requirements and vehicle architecture, i.e., identifying physical and functional matches or mismatches between the certification regulations and the vehicle architecture. The formalization of this approach as a model-based systems engineering approach to airworthiness certification is identified as potential means of coping with the growing complexity associated with the certification of novel aircraft systems. One critical outcome of such an approach is the systematic identification of potential gaps within this comparison, wherein no existing standard is applicable for a given vehicle concept. Furthermore, through the internal connectivity which underpins a model-based methodology, artifacts and data derived from technical requirements and documentation can be identified as candidates for filling in potential gaps. In these applications, the additional transparency and traceability afforded by a model-based approach would likely lend additional confidence to this overall certification process.

6 Recommendations for Future Work

In addition to the work represented in this report, four areas deserve further consideration.

6.1 Incorporate Finalized Mod IV Specifications and Requirements into a Revised AVP

This AVP report and the associated Compliance Artifact report benefited from solid specifications and requirements for the Mod II vehicle as it prepared for its risk-reduction flight research. Mod IV specifications and requirements were in development when this report was published. Revising this AVP report with updated, finalized requirements and specifications will significantly enhance the technologies associated with the Mod IV vehicle configuration. While the maturation of the technologies is a significant demonstration, the real value is the development of standards that reflect the maturity of the knowledge gained from the technology development.

6.2 Continue Development of Standards to Address New Means of Compliance

The early steps in developing standards based on the X-57 technologies are nascent in this report. As the Mod IV vehicle begins its flight research demonstration phase, many documents will be generated by NASA to conduct its design and readiness reviews. These documents will form the foundation for specifications, test methods, best practices, and fundamental data to build standards. NASA and its industry teammates will be unique in contributing significantly to developing standards for the ASTM and SAE committees in need of their insights.

6.3 Develop a Model-Based Systems Engineering Framework

A framework that supports deploying a model-based systems engineering approach to airworthiness certification should be developed. This framework would likely entail the engagement of relevant stakeholders within the airworthiness community. The development of the methods, tools, and model templates is well suited for aviation research organizations, including academia or government agencies like NASA. The construction and maintenance of certification regulations models would require SMEs' engagement within the FAA or similar agencies. At the same time, related development for airworthiness standards would likely be accomplished in coordination with relevant standards bodies. The application of model-based systems engineering would explicitly reveal how gaps in the regulations and standards are closed.

6.4 Engage the FAA Certification Policy and Innovation Team

The X-57 team has worked well with various technical experts from the FAA's Office of Policy and Innovation. Maintaining a continued close working relationship with the FAA technical experts is essential, including establishing a relationship with the FAA's Center for Emerging Concepts and Innovation (CECI).

7 Appendix A, Compliance Checklist for FAR 23, Subpart E, Powerplant

This appendix contains two tables: Table Subpart E-1. 14 CFR Part 23.400, Subpart E - Powerplant Airworthiness Certification Basis – FAA & ASTM F44 & F39 Standards Applicability to X-57 Distributed Electric Propulsion; and Table Subpart E-2 Top Level - EPU Powerplant Installation Certification Basis ASTM Standards Applicability & Relevance vs Part 23.2400.

These two tables form the basis upon which the report section on FAR 23, Subpart E, Powerplant, is written.

Table 5. 14 CFR Part 23.400, Subpart E - Powerplant Airworthiness Certification Basis – FAA & ASTM F44 & F39 Standards Applicability to X-57 Distributed Electric Propulsion

TABLE SUBPART E-1 14 CFR PART 23.400, SUBPART E - POWERPLANT AIRWORTHINESS CERTIFICATION BASIS – FAA & ASTM F44 STANDARDS APPLICABILITY TO X-57 DISTRIBUTED ELECTRIC PROPULSION							
14 CFR PART 23 SUBPART E APPLICABILITY				ASTM F44 STANDARDS APPLICABILITY			
14 PART 23 SECTION	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**	**ASTM STANDARD**	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**
§23.400	**Powerplant Installation**	YES		**F3062.F3062M-19**	**Standard Specification for Aircraft Powerplant Installation**	REF ONLY	Emphasis is traditional subsystem airworthiness.
	(a) For the purpose of this subpart, the airplane powerplant installation must include each component necessary for propulsion, which affects propulsion safety, or provides auxiliary power to the airplane.	YES	1) Distributed electrical propulsion requires system level assessment. See also 23.2410.		4. General §4.1 Engines & APU §4.2 Powerplant Installation	REF ONLY	ASTM D3062 Standard provides no additional specificity as compared to §23.400.
				F3065.F3065M-19	**Standard Specification for Aircraft Propeller System Installation**	REF	Supplemental to Part 23.
				F3239-19 draft	**Standard Specification for Aircraft Electric Propulsion Systems**	YES	
	(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	Yes	1) EPU type certificate requirements equivalent to Part 33 are yet to be defined. 2) Distributed electrical propulsion with multiple engines requires airworthiness assessment at both the engine	**F3062.F3062M-19**	**Standard Specification for Aircraft Powerplant Installation** No Applicable Section	REF ONLY	Airworthiness approval is not addressed by the ASTM Standard but rather is implied by the reference to the responsible CAA Body. ASTM Standard refers the user to the applicable CAA body.

TABLE SUBPART E-1 14 CFR PART 23.400, SUBPART E - POWERPLANT AIRWORTHINESS CERTIFICATION BASIS – FAA & ASTM F44 STANDARDS APPLICABILITY TO X-57 DISTRIBUTED ELECTRIC PROPULSION							
14 CFR PART 23 SUBPART E APPLICABILITY				**ASTM F44 STANDARDS APPLICABILITY**			
14 PART 23 SECTION	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**	**ASTM STANDARD**	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**
	accordance with a standard accepted by the FAA that contains airworthiness criteria the Administrator has 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.		and component level in addition to assessment at the system level of the integrated multiple engine propulsion system.	**F3338**	**Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft**	NO	No applicable section in current version as related to EPU type certificate.

TABLE SUBPART E-1 14 CFR PART 23.400, SUBPART E - POWERPLANT AIRWORTHINESS CERTIFICATION BASIS – FAA & ASTM F44 STANDARDS APPLICABILITY TO X-57 DISTRIBUTED ELECTRIC PROPULSION							
14 CFR PART 23 SUBPART E APPLICABILITY				**ASTM F44 STANDARDS APPLICABILITY**			
14 PART 23 SECTION	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**	**ASTM STANDARD**	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**
	(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.	YES	This section is fundamentally applicable to a distributed electrical propulsion system. F3062 Sect 4.2.1 requirements are an important cornerstone requirement for installation.	**F3062.F3062M-19 §4.1 - §4.2**	**Standard Specification for Aircraft Powerplant Installation** 4.2,1 Each powerplant installation must comply with the installation instructions of (1) the engine (2) the propeller if applicable (3) the APU if applicable. 4.2.2 Each powerplant installation must be constructed and arranged to ensure safe operation to the maximum altitude for which approval is requested. 4.2.3 Each turbine engine....... 4.2.4 Each powerplant installation	Supplemental to Part 23	Supplemental to Part 23. Incorporate compliance with requirements for Sect 4.2.1.
				F3338	**Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft** 1.2 Distributed propulsion is not excluded; however, additional requirements will be needed to address the additional issues that distributed propulsion can create. Some of those issues may include: use of a common motor controller/inverter, segregated electric harnesses, cooling systems, electric power	YES	Supplemental to Part 23.

TABLE SUBPART E-1 14 CFR PART 23.400, SUBPART E - POWERPLANT AIRWORTHINESS CERTIFICATION BASIS – FAA & ASTM F44 STANDARDS APPLICABILITY TO X-57 DISTRIBUTED ELECTRIC PROPULSION							
14 CFR PART 23 SUBPART E APPLICABILITY				ASTM F44 STANDARDS APPLICABILITY			
14 PART 23 SECTION	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**	**ASTM STANDARD**	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**
	(d) Hazardous accumulations of fluids, vapors, or gases must be isolated from the airplane and personnel compartments, and be safely contained or discharged.	YES	This section is fundamentally applicable to a distributed electrical propulsion system. See also 23.2320 (c) Occupant Physical Environment.	**F3066.F3066M-19**	Standard Specification for Aircraft Powerplant Installation Hazard Mitigation.	NOT APPLICABLE	Subject matter of 23.400(d) is not addressed by F3066.
	(e) Powerplant components must comply with their component limitations and installation instructions or be shown not to create a hazard.	YES	This section is fundamentally applicable to a distributed electrical propulsion system.	**F3062.F3062M-19**	Standard Specification for Aircraft Powerplant Installation §11. Powerplant Accessories & Components	REF	Content of §11 is supplemental to 23.400 (e).
				F3061/F3061M-19	Standard Specification for Systems & Equipment in Small Aircraft §4.1 Function & Installation	REF ONLY	Content of §4.1 is supplemental to 23.400 (e).
§23.2405	**Automatic power or thrust control systems.**	YES	Primary cert basis fundamentally applicable to a distributed electrical propulsion system.	**F3064/F306M-19**	Standard Specification for Aircraft Powerplant Installation Hazard Mitigation.	REF	Content is supplemental to 23.2405.
	(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.	YES	Primary cert basis fundamentally applicable to a distributed electrical propulsion system.	**F3064/F306M-19**	Standard Specification for Aircraft Powerplant Installation Hazard Mitigation. §5.9 Automatic Reserve §5.93 Reliability & Performance Requirements	REF	Content is supplemental to 23.2405.

TABLE SUBPART E-1 14 CFR PART 23.400, SUBPART E - POWERPLANT AIRWORTHINESS CERTIFICATION BASIS – FAA & ASTM F44 STANDARDS APPLICABILITY TO X-57 DISTRIBUTED ELECTRIC PROPULSION							
14 CFR PART 23 SUBPART E APPLICABILITY				ASTM F44 STANDARDS APPLICABILITY			
14 PART 23 SECTION	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**	**ASTM STANDARD**	**TITLE/ REQUIREMENT**	**APPLICABILITY TO X-57**	**COMMENTS**
	(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.	YES	Primary cert basis fundamentally applicable to a distributed electrical propulsion system.	**F3064/F306M-19**	Standard Specification for Aircraft Powerplant Installation Hazard Mitigation. §5.93 Reliability & Performance Requirements.	REF	Content is supplemental to 23.2405.
	(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.	YES	Primary cert basis fundamentally applicable to a distributed electrical propulsion system.				Content is supplemental to 23.2405.
	(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.	YES	Primary cert basis fundamentally applicable to a distributed electrical propulsion system.				

TABLE SUBPART E-1 14 CFR PART 23.400, SUBPART E - POWERPLANT AIRWORTHINESS CERTIFICATION BASIS – FAA & ASTM F44 STANDARDS APPLICABILITY TO X-57 DISTRIBUTED ELECTRIC PROPULSION							
14 CFR PART 23 SUBPART E APPLICABILITY				ASTM F44 STANDARDS APPLICABILITY			
14 PART 23 SECTION	TITLE/ REQUIREMENT	APPLICABILITY TO X-57	COMMENTS	ASTM STANDARD	TITLE/ REQUIREMENT	APPLICABILITY TO X-57	COMMENTS
§23.2410	**Powerplant Installation Hazard Assessment**	YES	Fundamentally applicable to a distributed electrical propulsion system.	**F3066/F3066M-19**	Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	REF	Requirements are supplemental to 23.2410.
	The applicant must 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.	YES	Fundamentally applicable to a distributed electrical propulsion system.	**F3066/F3066M-19**	Sect 5.4 Propellers and other components must be protected against the accumulation of ice.	N/A	Only Sections 5.4.

Table 6. Top Level - EPU Powerplant Installation Certification Basis ASTM Standards Applicability & Relevance vs Part 23.2400

TABLE SUBPART E-2 TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400											
14 CFR PART 23	**ASTM F44 STANDARDS**										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical Systems**
§23.2400 Powerplant installation.											
(a) 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.		✓			✓					✓ (??)	
(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.		✓	✓			✓					

TABLE SUBPART E-2
TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS
ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400

14 CFR PART 23	ASTM F44 STANDARDS										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical Systems**
(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 flight crew 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.				✓		✓				✓	

TABLE SUBPART E-2
TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS
ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400

14 CFR PART 23	**ASTM F44 STANDARDS**										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical Systems**
§23.2410 Powerplant installation hazard assessment.											
The applicant must 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.											

TABLE SUBPART E-2
TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS
ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400

14 CFR PART 23	**ASTM F44 STANDARDS**										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical 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.		✓		✓		✓				✓	
§23.2430 Fuel systems.	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
(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;	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

TABLE SUBPART E-2 TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400											
14 CFR PART 23	**ASTM F44 STANDARDS**										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical Systems**
(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;	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
(3) Provide the fuel necessary to ensure each powerplant and auxiliary power unit functions properly in all likely operating conditions;	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
(4) Provide the flight crew 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;	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
(5) Provide a means to safely remove or isolate the fuel stored in the system from the airplane;	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
(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	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
(7) Prevent hazardous contamination of the fuel supplied to each powerplant and auxiliary power unit.	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

TABLE SUBPART E-2
TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS
ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400

14 CFR PART 23	ASTM F44 STANDARDS										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical Systems**
(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.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(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	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(3) Prevent the occurrence of any hazard to the airplane or to persons during refilling or recharging.		✓	✓			✓				✓	

TABLE SUBPART E-2
TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS
ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400

14 CFR PART 23	ASTM F44 STANDARDS										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical Systems**
§23.2435 Powerplant induction and exhaust systems.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(a) The air induction system for each powerplant or auxiliary power unit and their accessories must—	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(1) Supply the air required by that powerplant or auxiliary power unit and its accessories under likely operating conditions;	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(2) Be designed to prevent likely hazards in the event of fire or backfire;	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(3) Minimize the ingestion of foreign matter; and	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(4) Provide an alternate intake if blockage of the primary intake is likely.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(b) The exhaust system, including exhaust heat exchangers for each powerplant or auxiliary power unit, must—	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(1) Provide a means to safely discharge potential harmful material; and	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(2) Be designed to prevent likely hazards from heat, corrosion, or blockage.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
§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.		✓	✓			✓				✓	

TABLE SUBPART E-2
TOP LEVEL - EPU POWERPLANT INSTALLATION CERT BASIS
ASTM STANDARDS APPLICABILITY & RELEVANCE vs PART 23.2400

14 CFR PART 23	ASTM F44 STANDARDS										
Subpart E—Powerplant	**F3061 System & Equipment**	**F3062 Powerplant Installation**	**F3063 Energy Storage**	**F3064 Control, Ops, Indication**	**F3065 Propeller Installation**	**F3066 Hazard Mitigation**	**F3114 Structures**	**F3116 Design Loads**	**F3120 Ice Protection**	**F3239 Electric Propulsion**	**F3316 Electrical Systems**
(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		✓	✓			✓				✓	

8 Appendix B, Means of Compliance Gap Analysis for Part 33, Aircraft Engines

This appendix contains the gap analysis of 14 CFR 33, Aircraft Engines to the existing Means of Compliance under ASTM F3338-20, alternate MOC using Advisory Circulars, and highlights of omissions in current MOC, along with recommendations.

Table 7. 14 CFR Part 33 Gap Analysis of Means of Compliance

Legend for Column #3

No action Required
Changes to ASTM F3338-20 Recommended
Recommend drafting of stand-alone MoC

14 CFR PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

FAR 33 / magniX Special Condition	Comment	#1, MoC from ASTM F39-F44	#2, alt MoC from ACs	#3, highlight omission & make recommendation
Subpart A—General				
§33.1 Applicability.	Remains applicable through the requirements of magniX special condition 1.	ASTM F3338-20 Section 5.0		Proposed magniX special condition 1 requires magniX to comply with 14 CFR part 33, except for those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines. Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.0 is complementary to the Regulation.
§33.3 General.				
§33.4 Instructions for Continued Airworthiness.	Remains applicable through the requirements of magniX special condition 1.	ASTM F3338-20 Section 5.1	AC 33.4-1; AC 33.4-3; AC33.27-1A; AC 33.70-1	Proposed magniX special condition 1 requires magniX to comply with 14 CFR part 33, except for those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines. Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.1 is complementary to the Regulation.
§33.5 Instruction manual for installing and operating the engine.	Remains applicable through the requirements of magniX special condition 1.	ASTM F3338-20 Section 5.2	AC 33-3	Proposed magniX special condition 1 requires magniX to comply with 14 CFR part 33, except for those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines. Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.2 is complementary to the Regulation.
§33.7 Engine ratings and operating limitations. **magniX special condition 2 also applies; see Section 3.2.2**	magniX special condition 1 applies except as explicitly superseded by magniX special condition 2.	ASTM F3338-20 Section 5.3		Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.3 is complementary to the special condition as modified by magniX special condition 2.
§33.8 Selection of engine power and thrust ratings.	Remains applicable through the requirements of magniX special condition 1.	ASTM F3338-20 Section 5.3.5 - 8		Proposed magniX special condition 1 requires magniX to comply with 14 CFR part 33, except for those airworthiness standards specifically and explicitly applicable only to reciprocating and turbine aircraft engines. Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.3.5 - 5.3.8 are complementary to the Regulation.
Subpart B—Design and Construction; General				
§33.11 Applicability.				
§33.13 [Reserved]				

14 CFR PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

FAR 33 / magniX Special Condition	Comment	#1, MoC from ASTM F39-F44	#2, alt MoC from ACs	#3, highlight omission & make recommendation
§33.15 Materials.	Remains fully applicable through the requirements of magniX special condition 3.	ASTM F3338-20 Section 5.4	AC 33.70-1	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.4 is complementary to the Regulation.
§33.17 Fire protection. **magniX special condition 4 also applies; see Section 3.2.2**	Remains applicable through the requirements of magniX special condition 4.	ASTM F3338-20 Section 5.5	AC33.17-1A	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.5 is complementary to the Regulation & special condition as modified by magniX special condition 4.
§33.19 Durability. **magniX special condition 5 supersedes; see Section 3.2.2**	Recommend changes to ASTM F3338-20 Section 5.6 to address the electric motor rotor cases which were addressed in §33.19 Durability.	ASTM F3338-20 Section 5.6	AC 33-2C; AC 33-5; AC 33.70-1	Recommend more prescriptive language to address the electric motor rotor in ASTM F3338-20 Section 5.6.
§33.21 Engine cooling. **magniX special condition 6 also applies; see Section 3.2.2**	Remains applicable through the requirements of magniX special condition 6.	ASTM F3338-20 Section 5.7	AC 33-2C	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.7 is complementary to the Regulation as modified by magniX special condition 6.
§33.23 Engine mounting attachments and structure.	Remains fully applicable through the requirements of magniX special condition 7. EASA CS-E 130 requires fireproof engine mounts. ASTM F3338-20 Section 5.8 has incorporated this requirement.	ASTM F3338-20 Section 5.8	AC 33-2C; AC33.17-1A	Assuming FAA acceptance of ASTM F3338-20 as a MoC, rely on the fireproof provision cited in ASTM F3338-20 or CS-E 130. Note the fireproof requirement exceeds FAA historical requirements.
§33.25 Accessory attachments.	Remains fully applicable through the requirements of magniX special condition 8.		AC 33-2C	Not addressed in ASTM F3338-20.
§33.27 Turbine, compressor, fan, and turbosupercharger rotor overspeed. **magniX special condition 9 supersedes; see Section 3.2.2**	Section 5.9.4 of ASTM F3338-20 introduces EPU-specific failure modes that could not be anticipated in 14 CFR 33.27 and its AC.	ASTM F3338-20 Section 5.9	AC 33.27-1A; AC 33-3; AC 33.70-1	Assuming FAA acceptance of ASTM F3338-20 as a MoC, an EPU test plan can likely be drafted which would preclude the need for an additional MoC.
§33.28 Engine control systems. **magniX special condition 10 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.10	AC 33.28-3; AC33.4-3	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.10 is complementary to the special condition. However, an historic perspective of AC 33.28-X points to a high likelihood that a revised version will be required. ASTM F3338-20 Section 5.10.4.2 specifies a non-exhaustive list of unacceptable EPU operating characteristics which should be considered.
§33.29 Instrument connection. **magniX special condition 11 also applies; see Section 3.2.2**	Portions of the Regulation remain fully applicable through the requirements of magniX special condition 11.	ASTM F3338-20 Section 5.11	AC 33-2C	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.11 is complementary to the Regulation.
~~**Subpart C—Design and Construction; Reciprocating Aircraft Engines**~~				Section not applicable
~~**Subpart D—Block Tests; Reciprocating Aircraft Engines**~~				Section not applicable

14 CFR PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

FAR 33 / magniX Special Condition	Comment	#1, MoC from ASTM F39-F44	#2, alt MoC from ACs	#3, highlight omission & make recommendation
Subpart E—Design and Construction; Turbine Aircraft Engines				
§33.61 Applicability.				
§33.62 Stress analysis. **magniX special condition 12 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.14		Assuming FAA acceptance of ASTM F3338-20as a MoC, ASTM F3338-20 Section 5.14 specifies additional electric stress boundary conditions which should be considered in the design.
~~§33.63 Vibration.~~	The magniX special condition has determined this Regulation is not applicable to their EPU. Similarities between the magniX EPU and X-57 EPU's make it feasible to apply the same logic to its certification.			
~~§33.64 Pressurized engine static parts.~~				
~~§33.65 Surge and stall characteristics.~~				
~~§33.66 Bleed air system.~~				
~~§33.67 Fuel system.~~				
~~§33.68 Induction system icing.~~				
~~§33.69 Ignitions system.~~				
§33.70 Engine life-limited parts. **magniX special condition 13 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.15.3	AC 33.70-1; AC33.27-1A	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.15.3 is complementary to the special condition.
§33.71 Lubrication system. **magniX special condition 14 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.16		Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.16 is complementary to the special condition. In many ways, this special condition is more prescriptive and richer in detail than the MoC proposed in F3338.
~~§33.72 Hydraulic actuating systems.~~	The magniX special condition has determined this Regulation is not applicable to their EPU. Similarities between the magniX EPU and X-57 EPU's make it feasible to apply the same logic to its certification.			
§33.73 Power or thrust response. **magniX special condition 15 supersedes; see Section 3.2.2**	Recommend more prescriptive language to address jam accels and decels.	ASTM F3338-20 Section 5.20.9		The treatment of jam accels and decels in ASTM F3338-20 Section 5.21.9 is inadequate. There should be more reliance on the prescriptive elements found in §33.73.
§33.74 Continued rotation. **magniX special condition 16 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.17		Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.17 specifies additional factors associated with back-EMF should be considered in the design.
§33.75 Safety analysis. **magniX special condition 17 also applies; see Section 3.2.2**	Portions of the Regulation remain fully applicable through the requirements of magniX special condition 17.	ASTM F3338-20 Section 5.19	AC 33.75-1A; AC 33.70-1	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.19 is complementary to the special condition.
§33.76 Bird ingestion. **magniX special condition 18 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.20		Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.20 specifies additional and EPU-unique failure modes that could result from foreign object

14 CFR PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

FAR 33 / magniX Special Condition	Comment	#1, MoC from ASTM F39-F44	#2, alt MoC from ACs	#3, highlight omission & make recommendation
§33.77 Foreign object ingestion—ice. **magniX special condition 18 supersedes; see Section 3.2.2**				ingestion. Further reference to 14 CFR 33.76 and 33.77 and 33.78 may be necessary to fully define an MoC.
§33.78 Rain and hail ingestion. **magniX special condition 18 supersedes; see Section 3.2.2**				
~~§33.79 Fuel burning thrust augmentor.~~	The magniX special condition has determined this Regulation is not applicable to their EPU. Similarities between the magniX EPU and X-57 EPU's make it feasible to apply the same logic to its certification.			
Subpart F—Block Tests; Turbine Aircraft Engines				
§33.81 Applicability.				
§33.82 General.				
§33.83 Vibration test. **magniX special condition 20 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.21.4	AC 33-83A	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.21.4 is complementary to the special condition.
§33.84 Engine overtorque test. **magniX special condition 21 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.21.5	AC 33-2C; AC33.87-1A	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.21.5 is complementary to the special condition.
§33.85 Calibration tests. **magniX special condition 22 supersedes; see Section 3.2.2**	The authors recommend the addition of specific tests outlined in IEC 60349-4 to the MoC, See Section 3.6.	ASTM F3338-20 Section 5.21.7	AC33.87-1A	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.21.7 is complementary to the special condition. However, the authors recommend the addition of specific IEC Tests to the MoC.
§33.87 Endurance test. **magniX special condition 23 supersedes; see Section 3.2.2**	Given the reasons laid out in Section 3.6.1 of this document, the authors encourage the continued use of the prescriptive guidance found in 14 CFR 33.87.	ASTM F3338-20 Section 5.21.3	AC33.87-1A	Both the Administrator and the Applicant would benefit from an MoC which provides both specificity and granularity to this block test.
§33.88 Engine overtemperature test. **magniX special condition 24 supersedes; see Section 3.2.2**	The authors encourage the use of the prescriptive guidance found in a mark-up of 14 CFR 33.88 found in Section 3.6.2.	ASTM F3338-20 Section 5.21.6	AC 33-2C	We disagree with the disclaimers in the ASTM standard that the test temperatures "must not violate the physical limitation of the permanent magnet material (curie-temperature including sufficient safety margin." The purpose of this test is to establish that margin exists.
§33.89 Operation test. **magniX special condition 25 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.21.8	AC 33-2C	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.21.8 is complementary to the special condition.

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FAR 33 / magniX Special Condition	Comment	#1, MoC from ASTM F39-F44	#2, alt MoC from ACs	#3, highlight omission & make recommendation
magniX special condition 26 Durability demonstration.	Durability is not specifically addressed in 14 CFR 33.	ASTM F3338-20 Section 5.21		Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.21.3 is complementary to the special condition. While durability is usually established on the basis of repetitive endurance tests, it is not unusual to separately negotiate the scope of a durability test.
§~~33.90 Initial maintenance inspection test.~~	A review of the original rulemaking explanation (14 CFR 33 Amendment 6) shows that the addition of magniX special condition 26, Durability demonstration, fulfills the intent of this Regulation.	ASTM F3338-20 Section 5.21		See magniX special condition 26, above.
§33.91 Engine system and component tests. **magniX special condition 27 supersedes; see Section 3.2.2**	This Regulation/special condition is retained to cover any eventualities wherein special system or component environment tests may be required.		AC 33.91-1	The Regulation/special condition should still apply but is not covered in ASTM F3338-20. The prescriptive language in the special condition is sufficient in scope.
§33.92 Rotor locking tests. **magniX special condition 28 supersedes; see Section 3.2.2**	A review of the original rulemaking explanation (14 CFR 33 Amendment 6) shows the original FAA intent was to require either satisfactory rotor windmilling without oil or a means to stop rotor windmilling. The proposal would also establish windmilling tests. (a) Unless means are incorporated in the engine to stop rotation of the engine rotors when the engine is shut down in flight, each engine rotor must be capable of rotating, for 3 hours at the limiting windmilling rotational RPM with no oil in the engine oil system, without the engine-- (1) Catching fire; (2) Bursting; or (3) Generating loads greater than those specified for compliance with Sec. 33.23 [Engine mount attachments & structure].. (b) An engine incorporating means to stop rotation of the engine rotors …	ASTM F3338-20 Section 5.22		Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.22 is complementary to the special condition.
§33.93 Teardown inspection. **magniX special condition 29 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.23	AC33.87-1A	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.23 specifies additional tests and measurements which should occur during teardown inspection.

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FAR 33 / magniX Special Condition	Comment	#1, MoC from ASTM F39-F44	#2, alt MoC from ACs	#3, highlight omission & make recommendation
§33.94 Blade containment and rotor unbalance tests. **magniX special condition 30 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.24	AC 20-128A; AC 33-5	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.24 is complementary to the special condition. In many ways, this special condition is more prescriptive and richer in detail than the MoC proposed in F3338.
§33.95 Engine-propeller systems tests. **magniX special condition 31 supersedes; see Section 3.2.2**		ASTM F3338-20 Section 5.25	AC 33-2C	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.25 is complementary to the special condition.
§33.96 Engine tests in auxiliary power unit (APU) mode.				Section not applicable
§33.97 Thrust reversers.		ASTM F3338-20 Section 5.25.1.3	AC 33-2C	Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.25.1.3 is complementary to the Regulation.
§33.99 General conduct of block tests.		ASTM F3338-20 Section 5.21.2		Assuming FAA acceptance of ASTM F3338-20 as a MoC, ASTM F3338-20 Section 5.21.2 is complementary to the Regulation.
Subpart G—Special Requirements: Turbine Aircraft Engines				Section not applicable

9 Appendix C, Certification Basis for Part 35, Propellers

This appendix contains the certification basis of 14 CFR 35, Propellers as if it were to be considered for the X-57.

The airplane will be certificated under 21.17 and incorporate the propeller requirements established for the airplane under 21.17. The base requirements for the propeller are FAR part 35 Amendment 10. The part 35 requirements are modified for propellers approved under the airplane type certificate. A propeller with a propeller type certificate may also be used as specified in §23.2400 Powerplant installation. Any additional requirements for the propeller not covered by part 35 will be noted.

Propeller Design Assumptions:

- Traction Propeller
    - Controllable
    - Variable pitch
    - Feathering
    - Reversing
    - Hydraulic pitch change actuation
    - Pitch bearing retention system
    - Double acting or single acting propeller pitch control system with or without counter weights
    - Approved under the airplane type certificate
- High-Lift Propeller
    - Fixed pitch
    - Pinned root retention
    - Stowed locking feature
    - Approved under the airplane type certificate

9.1 Certification Basis of X-57 to Part 35, Subpart A, General

The approach for Subpart A is to modify part 35 for the traction propellers and high-lift propellers and their applicability to the X-57.

Base Requirement **Subpart A—General**	**Traction Propeller**	**High-Lift Propeller**
§35.1 Applicability.		
(a) This part prescribes airworthiness standards for the issue of type certificates and changes to those certificates, for propellers.	(a) This part prescribes airworthiness standards for *propellers certificated with the airplane.* ~~*the issue of type certificates and changes to those certificates, for propellers.*~~	(a) This part prescribes airworthiness standards for *propellers certificated with the airplane.* ~~*the issue of type certificates and changes to those certificates, for propellers.*~~
	Comment: Modified for the propeller approved under the airplane type certificate.	Comment: Modified for the propeller approved under the airplane type certificate.
(b) Each person who applies under part 21 for such a certificate or change must show compliance with the applicable requirements of this part.		
	Comment: No Change	Comment: No Change
(c) An applicant is eligible for a propeller type certificate and changes to those certificates after demonstrating compliance with subparts A, B, and C of this part. However, the propeller may not be installed on an airplane unless the applicant has shown compliance with either §23.2400(c) or §25.907 of this chapter, as applicable, or compliance is not required for installation on that airplane.	~~*(c) An applicant is eligible for a propeller type certificate and changes to those certificates after demonstrating compliance with subparts A, B, and C of this part. However, the propeller may not be installed on an airplane unless the applicant has shown compliance with either §23.2400(c) or §25.907 of this chapter, as applicable, or compliance is not required for installation on that airplane.*~~	~~*(c) An applicant is eligible for a propeller type certificate and changes to those certificates after demonstrating compliance with subparts A, B, and C of this part. However, the propeller may not be installed on an airplane unless the applicant has shown compliance with either §23.2400(c) or §25.907 of this chapter, as applicable, or compliance is not required for installation on that airplane.*~~
	Comment: Delete, the propeller is approved under the airplane type certificate.	Comment: Delete, the propeller is approved under the airplane type certificate.

Base Requirement **Subpart A—General**	**Traction Propeller**	**High-Lift Propeller**
(d) For the purposes of this part, the propeller consists of those components listed in the propeller type design, and the propeller system consists of the propeller and all the components necessary for its functioning, but not necessarily included in the propeller type design. [ref: Amendment 35-3, 41 FR 55475, Dec. 20, 1976, as amended by Amendment 35-8, 73 FR 63346, Oct. 24, 2008; Doc. FAA-2015-1621, Amendment 35-10, 81 FR 96700, Dec. 30, 2016]	(d) For the purposes of this part, the propeller consists of those components listed in the propeller type design, and the propeller system consists of the propeller and all the components necessary for its functioning~~*, but not necessarily included in the propeller type design*~~.	(d) For the purposes of this part, the propeller consists of those components listed in the propeller type design, and the propeller system consists of the propeller and all the components necessary for its functioning~~*, but not necessarily included in the propeller type design*~~.
	Comment: Modified, the propeller is approved under the airplane type certificate.	Comment: Modified, the propeller is approved under the airplane type certificate.
§35.2 Propeller configuration.		
The applicant must provide 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 under §21.31 of this chapter. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]	The applicant must provide 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 under §*21.17*~~*31*~~ of this chapter.	The applicant must provide 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 under §*21.17*~~*31*~~ of this chapter.
	Comment: Modified, the propeller is approved under the airplane type certificate.	Comment: Modified, the propeller is approved under the airplane type certificate.
§35.3 Instructions for propeller installation and operation.		
The applicant must provide instructions that are approved by the Administrator. Those approved instructions must contain:	The applicant must provide instructions that are approved by the Administrator. Those approved instructions must contain:	The applicant must provide instructions that are approved by the Administrator. Those approved instructions must contain:
	Comment: No change	Comment: No change
(a) Instructions for installing the propeller, which:		
	Comment: No change	Comment: No change

Base Requirement **Subpart A—General**	**Traction Propeller**	**High-Lift Propeller**
(1) Include a description of the operational modes of the propeller control system and functional interface of the control system with the airplane and engine systems;		
	Comment: No change	Comment: No change
(2) Specify the physical and functional interfaces with the airplane, airplane equipment and engine;		
	Comment: No change	Comment: No change
(3) Define the limiting conditions on the interfaces from paragraph (a)(2) of this section;		
	Comment: No change	Comment: No change
(4) List the limitations established under §35.5;		
	Comment: No change	Comment: No change
(5) Define the hydraulic fluids approved for use with the propeller, including grade and specification, related operating pressure, and filtration levels; and		
	Comment: No change	Comment: No change
(6) State the assumptions made to comply with the requirements of this part.		
(b) Instructions for operating the propeller which must specify all procedures necessary for operating the propeller within the limitations of the propeller type design. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.4 Instructions for Continued Airworthiness.		

Base Requirement **Subpart A—General**	**Traction Propeller**	**High-Lift Propeller**
The applicant must prepare Instructions for Continued Airworthiness in accordance with appendix A to this part that are acceptable to the Administrator. The instructions may be incomplete at type certification if a program exists to ensure their completion prior to delivery of the first aircraft with the propeller installed, or upon issuance of a standard certificate of airworthiness for an aircraft with the propeller installed, whichever occurs later. [ref: Amendment 35-5, 45 FR 60181, Sept. 11, 1980]		
	Comment: No change	Comment: No change
§35.5 Propeller ratings and operating limitations.		
	Comment: No change	Comment: No change
(a) Propeller ratings and operating limitations must:		
	Comment: No change	Comment: No change
(1) Be established by the applicant and approved by the Administrator.		
	Comment: No change	Comment: No change
(2) Be included directly or by reference in the propeller type certificate data sheet, as specified in §21.41 of this chapter.	(2) Be included directly or by reference in the ~~propeller type certificate data sheet~~ *airplane type certificate data sheet*, as specified in §21.41 of this chapter.	(2) Be included directly or by reference in the ~~propeller type certificate data sheet~~ *airplane type certificate data sheet*, as specified in §21.41 of this chapter.
	Comment: Modified, the propeller is approved under the airplane type certificate	Comment: Modified, the propeller is approved under the airplane type certificate
(3) Be based on the operating conditions demonstrated during the tests required by this part as well as any other information the Administrator requires as necessary for the safe operation of the propeller.		
	Comment: No change	Comment: No change

Base Requirement **Subpart A—General**	**Traction Propeller**	**High-Lift Propeller**
(b) Propeller ratings and operating limitations must be established for the following, as applicable:	(b) Propeller ratings and operating limitations must be established for the *propeller* ~~*following*~~ *and approved by the Administrator*, as applicable:	(b) Propeller ratings and operating limitations must be established for the *propeller* ~~*following*~~ *and approved by the Administrator*, as applicable:
	Comment: The traditional power, rotational speed, takeoff and etc. may not be applicable for the propeller with an electric propulsion system.	Comment: The traditional power, rotational speed, takeoff and etc. may not be applicable for the propeller.
(1) Power and rotational speed:	~~*(1) Power and rotational speed:*~~	~~*(1) Power and rotational speed:*~~
	Comment: Delete.	Comment: Delete.
(i) For takeoff.	~~*(i) For takeoff.*~~	~~*(i) For takeoff.*~~
	Comment: Delete.	Comment: Delete.
(ii) For maximum continuous.	~~*(ii) For maximum continuous.*~~	~~*(ii) For maximum continuous.*~~
(iii) If requested by the applicant, other ratings may also be established.	~~*(iii) If requested by the applicant, other ratings may also be established.*~~	~~*(iii) If requested by the applicant, other ratings may also be established.*~~
	Comment: Delete.	Comment: Delete.
(2) Overspeed and overtorque limits. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]	~~*(2) Overspeed and overtorque limits.*~~	~~*(2) Overspeed and overtorque limits.*~~
	Comment: Delete.	Comment: Delete.
§35.7 Features and characteristics.		
(a) 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.		
	Comment: No change	Comment: No change

Base Requirement **Subpart A—General**	**Traction Propeller**	**High-Lift Propeller**
(b) If a failure occurs during a certification test, the applicant must determine the cause and assess the effect on the airworthiness of the propeller. The applicant must make changes to the design and conduct additional tests that the Administrator finds necessary to establish the airworthiness of the propeller. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008]	Comment: No change	Comment: No change

9.2 Certification Basis of X-57 to Part 35, Subpart B, Design and Construction

The approach for Subpart B is to modify part 35 for the traction propellers and high-lift propellers and their applicability to the X-57.

Subpart B—Design and Construction	**Traction Propellers**	**High-Lift Propellers**
§35.11 [Reserved]	~~*§35.11 [Reserved]*~~	~~*§35.11 [Reserved]*~~
	Comment: Delete	Comment: Delete
§35.13 [Reserved]	~~*§35.13 [Reserved]*~~	~~*§35.13 [Reserved]*~~
	Comment: Delete	Comment: Delete
§35.15 Safety analysis.		
(a)(1) The applicant must analyze the propeller system to assess the likely consequences of all failures that can reasonably be expected to occur. This analysis will take into account, if applicable:		
	Comment: No change	Comment: No change
(i) The propeller system in a typical installation. When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.	(i) The propeller system ~~*in a typical installation*~~ *installed on the airplane.* When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.	(i) The propeller system ~~*in a typical installation*~~ *installed on the airplane.* When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.
	Comment: Modified, the propeller is approved under the airplane type certificate.	Comment: Modified, the propeller is approved under the airplane type certificate.
(ii) Consequential secondary failures and dormant failures.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	**Traction Propellers**	**High-Lift Propellers**
(iii) Multiple failures referred to in paragraph (d) of this section, or that result in the hazardous propeller effects defined in paragraph (g)(1) of this section.		
	Comment: No change	Comment: No change
(2) The applicant must summarize those failures that could result in major propeller effects or hazardous propeller effects defined in paragraph (g) of this section, and estimate the probability of occurrence of those effects.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
(3) The applicant must show that hazardous propeller effects are not predicted to occur at a rate in excess of that defined as extremely remote (probability of 10^{-7} or less per propeller flight hour). Since the estimated probability for individual failures may be insufficiently precise to enable the applicant to assess the total rate for hazardous propeller effects, compliance may be shown by demonstrating that the probability of a hazardous propeller effect arising from an individual failure can be predicted to be not greater than 10^{-8} per propeller flight hour. In dealing with probabilities of this low order of magnitude, absolute proof is not possible and reliance must be placed on engineering judgment and previous experience combined with sound design and test philosophies.		
	Comment: No change	Comment: No change
(b) If significant doubt exists as to the effects of failures or likely combination of failures, the Administrator may require assumptions used in the analysis to be verified by test.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
(c) The primary failures of certain single propeller elements (for example, blades) cannot be sensibly estimated in numerical terms. If the failure of such elements is likely to result in hazardous propeller effects, those elements must be identified as propeller critical parts. For propeller critical parts, applicants must meet the prescribed integrity specifications of §35.16. These instances must be stated in the safety analysis.		
	Comment: No change	Comment: No change
(d) If reliance is placed on a safety system to prevent a failure progressing to hazardous propeller effects, the possibility of a safety system failure in combination with a basic propeller failure must be included in the analysis. Such a safety system may include safety devices, instrumentation, early warning devices, maintenance checks, and other similar equipment or procedures. If items of the safety system are outside the control of the propeller manufacturer, the assumptions of the safety analysis with respect to the reliability of these parts must be clearly stated in the analysis and identified in the propeller installation and operation instructions required under §35.3.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
(e) If the safety analysis depends on one or more of the following items, those items must be identified in the analysis and appropriately substantiated.		
	Comment: No change	Comment: No change
(1) Maintenance actions being carried out at stated intervals. This includes verifying that items that could fail in a latent manner are functioning properly. When necessary to prevent hazardous propeller effects, these maintenance actions and intervals must be published in the instructions for continued airworthiness required under §35.4. Additionally, if errors in maintenance of the propeller system could lead to hazardous propeller effects, the appropriate maintenance procedures must be included in the relevant propeller manuals.		
	Comment: No change	Comment: No change
(2) Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details of this satisfactory functioning must be published in the appropriate manual.		
	Comment: No change	Comment: No change
(3) The provision of specific instrumentation not otherwise required. Such instrumentation must be published in the appropriate documentation.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
(4) A fatigue assessment.		
	Comment: No change	Comment: No change
(f) If applicable, the safety analysis must include, but not be limited to, assessment of indicating equipment, manual and automatic controls, governors and propeller control systems, synchrophasers, synchronizers, and propeller thrust reversal systems.		
	Comment: No change	Comment: No change
(g) Unless otherwise approved by the Administrator and stated in the safety analysis, the following failure definitions apply to compliance with this part.		
	Comment: No change	Comment: No change
(1) The following are regarded as hazardous propeller effects:		
	Comment: No change	Comment: No change
(i) The development of excessive drag.		
	Comment: No change	Comment: No change
(ii) A significant thrust in the opposite direction to that commanded by the pilot.		
	Comment: No change	Comment: No change
(iii) The release of the propeller or any major portion of the propeller.		
	Comment: No change	Comment: No change
(iv) A failure that results in excessive unbalance.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	**Traction Propellers**	**High-Lift Propellers**
		(v) The inability to stow or unstow when required.
		Comment: New requirement for stowable propellers.
(2) The following are regarded as major propeller effects for variable pitch propellers:		
	Comment: No change	Comment: No change
(i) An inability to feather the propeller for feathering propellers.		
	Comment: No change	Comment: No change
(ii) An inability to change propeller pitch when commanded.		
	Comment: No change	Comment: No change
(iii) A significant uncommanded change in pitch.		
	Comment: No change	Comment: No change
(iv) A significant uncontrollable torque or speed fluctuation. [ref: Amendment 35-8, 73 FR 63346, Oct. 24, 2008, as amended by Amendment 35-9, 78 FR 4041, Jan. 18, 2013; Amendment 35-9A, 78 FR 45052, July 26, 2013]		
	Comment: No change	Comment: No change
§35.16 Propeller critical parts.		
The integrity of each propeller critical part identified by the safety analysis required by §35.15 must be established by:		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
(a) A defined engineering process for ensuring the integrity of the propeller critical part throughout its service life,		
	Comment: No change	Comment: No change
(b) A defined manufacturing process that identifies the requirements to consistently produce the propeller critical part as required by the engineering process, and		
	Comment: No change	Comment: No change
(c) A defined service management process that identifies the continued airworthiness requirements of the propeller critical part as required by the engineering process. [ref: Amendment 35-9, 78 FR 4042, Jan. 18, 2013]		
	Comment: No change	Comment: No change
§35.17 Materials and manufacturing methods.		
(a) The suitability and durability of materials used in the propeller must:		
	Comment: No change	Comment: No change
(1) Be established on the basis of experience, tests, or both.		
	Comment: No change	Comment: No change
(2) Account for environmental conditions expected in service.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	**Traction Propellers**	**High-Lift Propellers**
(b) All materials and manufacturing methods must conform to specifications acceptable to the Administrator.		
	Comment: No change	Comment: No change
(c) The design values of properties of materials must be suitably related to the most adverse properties stated in the material specification for applicable conditions expected in service. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§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.		
	Comment: No change	Comment: No change
§35.21 Variable and reversible pitch propellers.		

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
(a) No single failure or malfunction in the propeller system will result in unintended travel of the propeller blades to a position below the in-flight low-pitch position. The extent of any intended travel below the in-flight low-pitch position must be documented by the applicant in the appropriate manuals. Failure of structural elements need not be considered if the occurrence of such a failure is shown to be extremely remote under §35.15.		
	Comment: No change	Comment: No change
(b) For propellers incorporating a method to select blade pitch below the in-flight low pitch position, provisions must be made to sense and indicate to the flight crew that the propeller blades are below that position by an amount defined in the installation manual. The method for sensing and indicating the propeller blade pitch position must be such that its failure does not affect the control of the propeller. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.22 Feathering propellers.		

Subpart B—Design and Construction	**Traction Propellers**	**High-Lift Propellers**
(a) Feathering propellers are intended to feather from all flight conditions, taking into account expected wear and leakage. Any feathering and unfeathering limitations must be documented in the appropriate manuals.		
	Comment: No change	Comment: No change
(b) Propeller pitch control systems that use engine oil to feather must incorporate a method to allow the propeller to feather if the engine oil system fails.		
	Comment: No change	Comment: No change
(c) Feathering propellers must be designed to be capable of unfeathering after the propeller system has stabilized to the minimum declared outside air temperature. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]		
	Comment: No change	Comment: No change
		§35.TBD Stowable propellers.
		(a) Stowable propellers are intended to stow and unstow as required by the phase of flight.
		Comment: The ability to stow and unstow has been written for a propeller that is certified with the airplane and the phase of flight is known.

Subpart B—Design and Construction	**Traction Propellers**	**High-Lift Propellers**
§35.23 Propeller control system.		
The requirements of this section apply to any system or component that controls, limits or monitors propeller functions.		
	Comment: No change	Comment: No change
(a) The propeller control system must be designed, constructed and validated to show that:		
	Comment: No change	Comment: No change
(1) The propeller control system, operating in normal and alternative operating modes and in transition between operating modes, performs the functions defined by the applicant throughout the declared operating conditions and flight envelope.		
	Comment: No change	Comment: No change
(2) The propeller control system functionality is not adversely affected by the declared environmental conditions, including temperature, electromagnetic interference (EMI), high intensity radiated fields (HIRF) and lightning. The environmental limits to which the system has been satisfactorily validated must be documented in the appropriate propeller manuals.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
(3) A method is provided to indicate that an operating mode change has occurred if flight crew action is required. In such an event, operating instructions must be provided in the appropriate manuals.		
	Comment: No change	Comment: No change
(b) The propeller control system must be designed and constructed so that, in addition to compliance with §35.15:		
	Comment: No change	Comment: No change
(1) No single failure or malfunction of electrical or electronic components in the control system results in a hazardous propeller effect.		
	Comment: No change	Comment: No change
(2) Failures or malfunctions directly affecting the propeller control system in a typical airplane, such as structural failures of attachments to the control, fire, or overheat, do not lead to a hazardous propeller effect.		
	Comment: No change	Comment: No change
(3) The loss of normal propeller pitch control does not cause a hazardous propeller effect under the intended operating conditions.		
	Comment: No change	Comment: No change
(4) The failure or corruption of data or signals shared across propellers does not cause a hazardous propeller effect.		
	Comment: No change	Comment: No change

Subpart B—Design and Construction	**Traction Propellers**	**High-Lift Propellers**
(c) Electronic propeller control system imbedded software must be designed and implemented by a method approved by the Administrator that is consistent with the criticality of the performed functions and that minimizes the existence of software errors.		
	Comment: No change	Comment: No change
(d) The propeller control system must be designed and constructed so that the failure or corruption of airplane-supplied data does not result in hazardous propeller effects.		
	Comment: No change	Comment: No change
(e) The propeller control system must be designed and constructed so that the loss, interruption or abnormal characteristic of airplane-supplied electrical power does not result in hazardous propeller effects. The power quality requirements must be described in the appropriate manuals. [ref: Amendment 35-8, 73 FR 63347, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.24 Strength.		

Subpart B—Design and Construction	Traction Propellers	High-Lift Propellers
The maximum stresses developed in the propeller may not exceed values acceptable to the Administrator considering the particular form of construction and the most severe operating conditions. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]		
	Comment: No change	Comment: No change

9.3 Certification Basis of X-57 to Part 35, Subpart C, Tests and Inspections

The approach for Subpart C is to modify part 35 for the traction propellers and high-lift propellers and their applicability to the X-57.

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
§35.31 [Reserved]	~~*§35.31 [Reserved]*~~	~~*§35.31 [Reserved]*~~
	Comment: Delete	Comment: Delete
§35.33 General.		
(a) Each applicant must furnish test article(s) and suitable testing facilities, including equipment and competent personnel, and conduct the required tests in accordance with part 21 of this chapter.		
	Comment: No change	Comment: No change
(b) All automatic controls and safety systems must be in operation unless it is accepted by the Administrator as impossible or not required because of the nature of the test. If needed for substantiation, the applicant may test a different propeller configuration if this does not constitute a less severe test.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
(c) Any systems or components that cannot be adequately substantiated by the applicant to the requirements of this part are required to undergo additional tests or analysis to demonstrate that the systems or components are able to perform their intended functions in all declared environmental and operating conditions. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.34 Inspections, adjustments and repairs.		
(a) Before and after conducting the tests prescribed in this part, the test article must be subjected to an inspection, and a record must be made of all the relevant parameters, calibrations and settings.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
(b) During all tests, only servicing and minor repairs are permitted. If major repairs or part replacement is required, the Administrator must approve the repair or part replacement prior to implementation and may require additional testing. Any unscheduled repair or action on the test article must be recorded and reported. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.35 Centrifugal load tests.		
The applicant must 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. This section does not apply to fixed-pitch wood or fixed-pitch metal propellers of conventional design.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
(a) The hub, blade retention system, and counterweights must be tested for a period of one hour to a load equivalent to twice the maximum centrifugal load to which the propeller would be subjected during operation at the maximum rated rotational speed.		
	Comment: No change	Comment: No change
(b) Blade features associated with transitions to the retention system (for example, a composite blade bonded to a metallic retention) must be tested either during the test of paragraph (a) of this section or in a separate component test for a period of one hour to a load equivalent to twice the maximum centrifugal load to which the propeller would be subjected during operation at the maximum rated rotational speed.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
(c) Components used with or attached to the propeller (for example, spinners, de-icing equipment, and blade erosion shields) must be subjected to a load equivalent to 159 percent of the maximum centrifugal load to which the component would be subjected during operation at the maximum rated rotational speed. This must be performed by either:		
	Comment: No change	Comment: No change
(1) Testing at the required load for a period of 30 minutes; or		
	Comment: No change	Comment: No change
(2) Analysis based on test. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.36 Bird impact.		

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
The applicant must 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. This section does not apply to fixed-pitch wood propellers of conventional design. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.37 Fatigue limits and evaluation.		
This section does not apply to fixed-pitch wood propellers of conventional design.		
	Comment: No change	Comment: No change
(a) Fatigue limits must be established by tests, or analysis based on tests, for propeller:		
(1) Hubs.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
(2) Blades.		
	Comment: No change	Comment: No change
(3) Blade retention components.		
	Comment: No change	Comment: No change
(4) Components which are affected by fatigue loads and which are shown under §35.15 to have a fatigue failure mode leading to hazardous propeller effects.		
	Comment: No change	Comment: No change
(b) The fatigue limits must take into account:		
	Comment: No change	Comment: No change
(1) All known and reasonably foreseeable vibration and cyclic load patterns that are expected in service; and		
	Comment: No change	Comment: No change
(2) Expected service deterioration, variations in material properties, manufacturing variations, and environmental effects.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
(c) A fatigue evaluation of the propeller must be conducted to show that hazardous propeller effects due to fatigue will be avoided throughout the intended operational life of the propeller on either:		
	Comment: No change	Comment: No change
(1) The intended airplane by complying with §23.2400(c) or §25.907 of this chapter, as applicable; or	(1) The intended airplane by complying with §23.2400(c) ~~or §25.907~~ of this chapter, as applicable~~; or~~	(1) The intended airplane by complying with §23.2400(c) ~~or §25.907~~ of this chapter, as applicable~~; or~~
	Comment: Modified, the propeller is approved under the airplane type certificate.	Comment: Modified, the propeller is approved under the airplane type certificate.
(2) A typical airplane. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008, as amended by Doc. FAA-2015-1621, Amendment 35-10, 81 FR 96700, Dec. 30, 2016]	~~*(2) A typical airplane*~~.	~~*(2) A typical airplane*~~
	Comment: Delete	Comment: Delete
§35.38 Lightning strike.		

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
The applicant must 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. The limit to which the propeller has been qualified must be documented in the appropriate manuals. This section does not apply to fixed-pitch wood propellers of conventional design. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]		
	Comment: Not applicable	Comment: Not applicable
§35.39 Endurance test.		
Endurance tests on the propeller system must be made on a representative engine in accordance with paragraph (a) or (b) of this section, as applicable, without evidence of failure or malfunction.		
	Comment: No change	Comment: No change
(a) Fixed-pitch and ground adjustable-pitch propellers must be subjected to one of the following tests:		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
(1) A 50-hour flight test in level flight or in climb. The propeller must be operated at takeoff power and rated rotational speed during at least five hours of this flight test, and at not less than 90 percent of the rated rotational speed for the remainder of the 50 hours.		
	Comment: No change	Comment: No change
(2) A 50-hour ground test at takeoff power and rated rotational speed.		
	Comment: No change	Comment: No change
(b) Variable-pitch propellers must be subjected to one of the following tests:		
	Comment: No change	Comment: No change
(1) A 110-hour endurance test that must include the following conditions:		
	Comment: No change	Comment: No change
(i) Five hours at takeoff power and rotational speed and thirty 10-minute cycles composed of:		
	Comment: No change	Comment: No change
(A) Acceleration from idle,		
	Comment: No change	Comment: No change
(B) Five minutes at takeoff power and rotational speed,		

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
	Comment: No change	Comment: No change
(C) Deceleration, and		
	Comment: No change	Comment: No change
(D) Five minutes at idle.		
	Comment: No change	Comment: No change
(ii) Fifty hours at maximum continuous power and rotational speed,		
	Comment: No change	Comment: No change
(iii) Fifty hours, consisting of ten 5-hour cycles composed of:		
	Comment: No change	Comment: No change
(A) Five accelerations and decelerations between idle and takeoff power and rotational speed,		
	Comment: No change	Comment: No change
(B) Four and one half hours at approximately even incremental conditions from idle up to, but not including, maximum continuous power and rotational speed, and		
(C) Thirty minutes at idle.	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
(2) The operation of the propeller throughout the engine endurance tests prescribed in part 33 of this chapter.		
	Comment: No change	Comment: No change
(c) An analysis based on tests of propellers of similar design may be used in place of the tests of paragraphs (a) and (b) of this section. [ref: Amendment 35-8, 73 FR 63348, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.40 Functional test.		
The 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. This test may be combined with the endurance test for accumulation of cycles.		

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
	Comment: No change	Comment: No change
(a) Manually-controllable propellers. Five hundred representative flight cycles must be made across the range of pitch and rotational speed.		
	Comment: No change	Comment: No change
(b) Governing propellers. Fifteen hundred complete cycles must be made across the range of pitch and rotational speed.		
	Comment: No change	Comment: No change
(c) Feathering propellers. Fifty cycles of feather and unfeather operation must be made.		
	Comment: No change	Comment: No change
(d) Reversible-pitch propellers. Two hundred complete cycles of control must be made from lowest normal pitch to maximum reverse pitch. During each cycle, the propeller must run for 30 seconds at the maximum power and rotational speed selected by the applicant for maximum reverse pitch.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
(e) An analysis based on tests of propellers of similar design may be used in place of the tests of this section. [ref: Amendment. 35-8, 73 FR 63349, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.41 Overspeed and overtorque.		
(a) When the applicant seeks approval of a transient maximum propeller overspeed, the applicant must demonstrate that the propeller is capable of further operation without maintenance action at the maximum propeller overspeed condition. This may be accomplished by:		
	Comment: No change	Comment: No change
(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overspeed condition; or		
	Comment: No change	Comment: No change
(2) Analysis based on test or service experience.		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
(b) When the applicant seeks approval of a transient maximum propeller overtorque, the applicant must demonstrate that the propeller is capable of further operation without maintenance action at the maximum propeller overtorque condition. This may be accomplished by:		
	Comment: No change	Comment: No change
(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overtorque condition; or		
	Comment: No change	Comment: No change
(2) Analysis based on test or service experience. [ref: Amendment 35-8, 73 FR 63349, Oct. 24, 2008]		
	Comment: No change	Comment: No change

Subpart C—Tests and Inspections	Traction Propellers	High-Lift Propellers
§35.42 Components of the propeller control system.		
	Comment: No change	Comment: No change
The applicant must 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. [ref: Amendment 35-8, 73 FR 63349, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§35.43 Propeller hydraulic components.		

Subpart C—Tests and Inspections	**Traction Propellers**	**High-Lift Propellers**
Applicants must 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 by:		
	Comment: No change	Comment: No change
(a) A proof pressure test to 1.5 times the maximum operating pressure for one minute without permanent deformation or leakage that would prevent performance of the intended function.		
	Comment: No change	Comment: No change
(b) A burst pressure test to 2.0 times the maximum operating pressure for one minute without failure. Leakage is permitted and seals may be excluded from the test. [ref: Amendment 35-8, 73 FR 63349, Oct. 24, 2008]		
	Comment: No change	Comment: No change
§§35.45-35.47 [Reserved]	~~*§§35.45-35.47 [Reserved]*~~	~~*§§35.45-35.47 [Reserved]*~~
	Comment: Delete	Comment: Delete

9.4 Certification Basis of X-57 to Appendix A to Part 35, Instructions for Continued Airworthiness

The approach for Instructions for Continued Airworthiness (ICA) is to modify part 35 for the traction Propellers and high-lift lropellers and their applicability to the X-57.

Appendix A to Part 35—Instructions for Continued Airworthiness	**Traction Propellers**	**High-Lift Propellers**
a35.1 general		
(a) This appendix specifies requirements for the preparation of Instructions for Continued Airworthiness as required by §35.4.		
	Comment: No change	Comment: No change
(b) The Instructions for Continued Airworthiness for each propeller must include the Instructions for Continued Airworthiness for all propeller parts. If Instructions for Continued Airworthiness are not supplied by the propeller part manufacturer for a propeller part, the Instructions for Continued Airworthiness for the propeller must include the information essential to the continued airworthiness of the propeller.		
	Comment: No change	Comment: No change

Appendix A to Part 35—Instructions for Continued Airworthiness	Traction Propellers	High-Lift Propellers
(c) The applicant must submit to the FAA a program to show how changes to the Instructions for Continued Airworthiness made by the applicant or by the manufacturers of propeller parts will be distributed.		
	Comment: No change	Comment: No change
a35.2 format		
(a) The Instructions for Continued Airworthiness must be in the form of a manual or manuals as appropriate for the quantity of data to be provided.		
	Comment: No change	Comment: No change
(b) The format of the manual or manuals must provide for a practical arrangement.		
	Comment: No change	Comment: No change
a35.3 content		

Appendix A to Part 35—Instructions for Continued Airworthiness	**Traction Propellers**	**High-Lift Propellers**
The contents of the manual must be prepared in the English language. The Instructions for Continued Airworthiness must contain the following sections and information:		
	Comment: No change	Comment: No change
(a) Propeller Maintenance Section. (1) Introduction information that includes an explanation of the propeller's features and data to the extent necessary for maintenance or preventive maintenance.		
	Comment: No change	Comment: No change
(2) A detailed description of the propeller and its systems and installations.		
	Comment: No change	Comment: No change
(3) Basic control and operation information describing how the propeller components and systems are controlled and how they operate, including any special procedures that apply.		
	Comment: No change	Comment: No change
(4) Instructions for uncrating, acceptance checking, lifting, and installing the propeller.		
	Comment: No change	Comment: No change

Appendix A to Part 35—Instructions for Continued Airworthiness	Traction Propellers	High-Lift Propellers
(5) Instructions for propeller operational checks.		
	Comment: No change	Comment: No change
(6) Scheduling information for each part of the propeller that provides the recommended periods at which it should be cleaned, adjusted, and tested, the applicable wear tolerances, and the degree of work recommended at these periods. However, the applicant may refer to an accessory, instrument, or equipment manufacturer as the source of this information if it shows that the item has an exceptionally high degree of complexity requiring specialized maintenance techniques, test equipment, or expertise. The recommended overhaul periods and necessary cross-references to the Airworthiness Limitations section of the manual must also be included. In addition, the applicant must include an inspection program that includes the frequency and extent of the inspections necessary to provide for the continued airworthiness of the propeller.		
	Comment: No change	Comment: No change

Appendix A to Part 35—Instructions for Continued Airworthiness	**Traction Propellers**	**High-Lift Propellers**
(7) Troubleshooting information describing probable malfunctions, how to recognize those malfunctions, and the remedial action for those malfunctions.		
	Comment: No change	Comment: No change
(8) Information describing the order and method of removing and replacing propeller parts with any necessary precautions to be taken.		
	Comment: No change	Comment: No change
(9) A list of the special tools needed for maintenance other than for overhauls.		
	Comment: No change	Comment: No change
(b) Propeller Overhaul Section. (1) Disassembly information including the order and method of disassembly for overhaul.		
	Comment: No change	Comment: No change
(2) Cleaning and inspection instructions that cover the materials and apparatus to be used and methods and precautions to be taken during overhaul. Methods of overhaul inspection must also be included.		
	Comment: No change	Comment: No change

Appendix A to Part 35—Instructions for Continued Airworthiness	**Traction Propellers**	**High-Lift Propellers**
(3) Details of all fits and clearances relevant to overhaul.		
	Comment: No change	Comment: No change
(4) Details of repair methods for worn or otherwise substandard parts and components along with information necessary to determine when replacement is necessary.		
	Comment: No change	Comment: No change
(5) The order and method of assembly at overhaul.		
	Comment: No change	Comment: No change
(6) Instructions for testing after overhaul.		
	Comment: No change	Comment: No change
(7) Instructions for storage preparation including any storage limits.		
	Comment: No change	Comment: No change
(8) A list of tools needed for overhaul.		
	Comment: No change	Comment: No change
a35.4 airworthiness limitations section		

Appendix A to Part 35—Instructions for Continued Airworthiness	**Traction Propellers**	**High-Lift Propellers**
The Instructions for Continued Airworthiness must contain a section titled Airworthiness Limitations that is segregated and clearly distinguishable from the rest of the document. This section must set forth each mandatory replacement time, inspection interval, and related procedure required for type certification. This section must contain a legible statement in a prominent location that reads: "The Airworthiness Limitations section is FAA approved and specifies maintenance required under §§43.16 and 91.403 of the Federal Aviation Regulations unless an alternative program has been FAA approved." [ref: Amendment 35-5, 45 FR 60182, Sept. 11, 1980, as amended by Amendment 35-6, 54 FR 34330, Aug. 18, 1989]		
	Comment: No change	Comment: No change

10 Appendix D, X-57 Configurations for Airworthiness Certification Airspeed Development

10.1 X-57 Stall Speed (VSO, VS1) and Minimum control Speed (VMC) Development for Field Performance Testing and Data Development

ASTM F3179/F3179M paragraphs 5, 6, 7, 13, 15, 16, 18 describe required testing for field performance and climb data development used to sow compliance to 14CFR Part 23 [23-64]. A prerequisite for field performance and climb speed development is completion of stall speed and minimum control speed development. ASTMs F317/F3179M use these speeds as a basis for defining minimum takeoff and landing speeds, along with climb speeds. Additionally, climb speed/data development requires AEO and OEI climb data to show compliance to 14CFR Part 23 [23-64].

Part of stall speed/VMC development is defining the power setting and configuration for each required flight condition for which compliance must be shown. Given the X-57 unique design, power settings and engine/airframe configurations must be well-understood and agreed upon by the certifying authority. For the X-57, state of HLP system and CM system in addition to gear/flap positions for each phase of flight must be defined.

Below is notional configuration matrix that would be required for stall speed/VMC testing.

Phase of Flight	**HLP**	**CM**	**Flaps**	**Gear**	**Notes**
Takeoff	Operating	Operating	TO	DN	HLP set to RPM is assumed. CM at 65% MCP assumed. Are several flap settings proposed for takeoff?
Takeoff Climb	Operating	Operating	TO	UP	HLP setting? AIRSPEED mode selected when? CM to MCP once takeoff phase is complete?
Cruise Climb	Stowed	Operating	UP	UP	CM at MCP? When are HLP deselected after DiTTO?
Cruise	Stowed	Operating	UP	UP	Variable CM Tq as required with fixed RPM?
Descent	Stowed	Operating	UP	UP	Variable CM as required?
Approach	Operating	Operating	APP	UP	When is HLP selected? What mode? Airspeed or RPM?
Landing	Operating	Operating	LAND	DN	When are LND flaps selected? Landing assured? HLP disconnected when?
Balked Landing	Operating	Operating	LAND	UP	HLP Mode? Airspeed or RPM? Is a pilot action required on the go?

10.2 10.2 HLP/CM States for Airworthiness Certification Testing

In addition to understanding power/configurations for each phase of flight, the following parameters must be defined and agreed upon with the certifying authority.

Parameter	**HLP**	**CM**	**Notes**
Power-Off for stall speed testing	X (Which mode…RPM or airspeed)	Idle	HLP mode(s)?
Power-On for stall speed testing	X	MCP unless excessive attitude is encountered	HLP both on and Off? NASA papers infer that HLP Off stall speeds need to be determined.
Engine Inoperative	Do HLP automatically stow upon failure?	One CM out? Propeller featherable manually or automatically? Which motor is the "critical motor"?	No rudder bias or ATI correct?
All-Engines Operating	X (depending on phase of flight)	X. Power setting for takeoff climb, cruise climb, balked landing climb? Using DiTTO, transition to CM MCP when after takeoff?	Flaps UP is stipulated engine-out climb performance. HLP mode(s)?

ASTM standard F3180/F3180M and 14 CFR 23.2110 requires stall speed development for each operational configuration proposed. As such, the stall speed matrix can be sizable given the various configurations and power settings available for each operational phase of flight.

A fundamental question arises concerning the operating concept of the HLP. Is the HLP system considered a high lift device like slats? Classification of the HLP system is key to treatment of the system for certification purposes.