D2.2: Certification basis composition report

October, 2018

Disclaimer

EXECUTIVE SUMMARY

Electric and Hybrid-Electric propulsion in the context of aviation has picked up incredible and unprecedented momentum. The design space enabled by power dense electric motors, lightweight power controllers and the fact that the power source on board the flying vehicle can be dislocated from the elements producing thrust is opening up new possibilities and classes of vehicle never seen before. While there are small, light-sport class, two-seat electric airplanes already flying, the push towards larger vehicles, distributed electric propulsion and new shape/form of aircraft is clear.

EASA CS-23 Amendment 5 has a built-in principle of being able to adopt industrial consensus standards as Acceptable Means of Compliance (AMC) and has already recognised work of ASTM Working Group F44, which caters standards for general aviation aircraft, also working in a standard for integration of electric and hybrid electric propulsion to general aviation airplanes. Given the principle that other standards could also, pending EASA approval, be used as AMC, this document on its own can serve as guidelines towards certification of future CS-23 electric and/or hybrid powered airplanes.

The intent of this document is to outline the fields in the process of aircraft type certification, which are not covered by current rules and require more attention in the future. There is also considerable effort to be made in advancing the Flight/Maintenance Crew Licences to include electric and hybrid electric aircraft, as well as work in the field of Operations – these are not covered by this document.

The document gives potential language for certification basis related to powerplant, batteries and their installation to the airframe. MAHEPA prototypes will use the paragraphs as a baseline for their airworthiness capability demonstration, with certain requirements surely evolving during the ground and test campaigns themselves. For what is known MAHEPA prototypes will be the first to utilise the proposed ASTM coordinated standardisation language and validate future applicable means of compliance to EASA CS-23, thus bringing value to future Type Certificate applicants across the board.

This documents version is currently foreseen to go in year 2019 under a joint revision Pipistrel-EASA in the scope of MAHEPA project and will be re-published in Q1 2020 with the revision results.

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Author(s)	Tine Tomažič (Pipistrel), Jure Tomažič (Pipistrel)
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ABBREVIATIONS

A list of abbreviations is strongly recommended.

AMC – Acceptable Means of Compliance

APU – Range extender power generator

ASTM – American Society for Testing and Materials

COTS – Commercial off the shelf

EASA – European Aviation Safety Agency

EPU – Electric Propulsion Units

ESS – Energy Storage System

T4S – Technology-for-Safety

INTRODUCTION

Electric and Hybrid-Electric propulsion in the context of aviation has picked up incredible and unprecedented momentum. The design space enabled by power dense electric motors, lightweight power controllers and the fact that the power source on board the flying vehicle can be dislocated from the elements producing thrust is opening up new possibilities and classes of vehicle never seen before. While there are small, light-sport class, two-seat electric airplanes already flying, the push towards larger vehicles, distributed electric propulsion and new shape/form of aircraft is clear.

Part-23 category of aircraft, governing technical, operational, crew and maintenance aspects of general aviation (2-19 seats) has gone through revitalization between 2011 and 2017 with EASA. In particular, technical requirements for the airplanes have been updated and are now manifested in CS-23 Amendment 5 document, which contains enabling language to introduce electric and hybrid propulsion. Lately, in June 2018, the new European Basic Regulation, governing aviation in general, has been passed with further important inclusions for electric flight (drones, principles of industrial consensus standards, use of non-type-certified propulsion systems with demonstrated characteristics on small aircraft, use of commercial-off-the-shelf equipment and more. A discussion worth mentioning is also the work of EASA Technology-for-Safety (T4S) group, which is establishing the concept of Net Safety Benefit to enable faster introduction of novel technology and features in the context of aviation and safety analyses. Pipistrel has been an active participant in all of the above.

CS-23 Amendment 5 has a built-in principle of being able to adopt industrial consensus standards as Acceptable Means of Compliance (AMC) and has already recognised work of ASTM Working Group F44, which caters standards for general aviation aircraft, also working in a standard for integration of electric and hybrid electric propulsion to general aviation airplanes. Given the principle that other standards could also, pending EASA approval, be used as AMC, this document on its own can serve as guidelines towards certification of future CS-23 electric and/or hybrid powered airplanes.

The intent of this document is to outline the fields in the process of aircraft type certification, which are not covered by current rules and require more attention in the future. There is also considerable effort to be made in advancing the Flight/Maintenance Crew Licences to include electric and hybrid electric aircraft, as well as work in the field of Operations – these are not covered by this document.

The lack of certification criteria for hybrid powertrains will be addressed by directly involving EASA as third party (confirmation of ‘EASA status as third party providing in-kind contributions against payment’ is available on request) in the selection of regulation subsets applicable to hybrid powertrains. By considering existing regulations (e.g. CSE, CS-23, DO-160, DO-178, DO-254, DO-311, ASTM 2840, EASA Special Conditions) the participants and EASA will seek an optimal mix between safety and simplicity in order to establish a certification basis and guidance material.

The output of this task will be beneficial for consortium partners' exploitation plans but also indirectly for the whole European Aviation industry by setting a much-awaited benchmark case on hybrid electric propulsion. The current version is expected to be revised with the contribution of EASA and republished in its final form in the beginning of 2020.

1. POWERPLANT (ENGINE) TYPE CERTIFICATION

1.1. INTRODUCTION

Currently in 2018 it appears that the consensus has been achieved as to what encompasses a (hybrid)-electric powerplant, and that the following:

- Electric motor with associated power electronics
- Battery
- Range extender power generator (APU)

shall be handled differently and separately in lieu of product certification. While the certification of Range extender power generators (APUs) is solidly covered by EASA CS-APU and will only require minor adaptations to cover the situations where the APU is utilized for providing primary power for sustained flight, the situation is much less clear for electric motors / power electronics and the battery. MAHEPA develops both and it was evident early-on in the project that the industry needs a clearer path to achieve production of approved/type certified components.

1.2. ELECTRIC MOTOR WITH ASSOCIATED POWER ELECTRONICS

Currently only ASTM F2840 provides high-level requirements for electric propulsion motors, which are stipulated with performance based language. No AMC exists, therefore electric motor design relies on best engineering practices from lightweight electric motor design (automotive SAE Standards) and applying analogies for sensible turbine-engines features as set forth by CS-E. ASTM's Working Group under committee F39.05, WK47374, which Pipistrel is a member of, has concluded work on requirements for air-cooled electric motor (as they are the simplest form) and is currently adding requirements for liquid cooled designs.

MAHEPA electric motor and power electronics have been designed according to best engineering judgements and applies solutions to the proposed requirements, which are in line with ASTM F39.05/F44.40 activities that Pipistrel is contributing to. Therefore, in the spirit of future ASTM standards, the numbering on the following sectons is followoing the expected section numbering in the standards.

5.3 EPU ratings and operating limitations

Note: Ratings will be established and presented in terms of power.

5.3.1 EPU ratings and operating limitations are established as applicable, including:

- Power, torque, speed, and time for—
- Rated maximum continuous power
- Rated takeoff power
- Maximum Transient rotor shaft overspeed and time
- Maximum Transient EPU overtorque and time, and number of overtorque occurrences
- Maximum EPU overtorque and time
- Electrical power, voltage, current, frequency and electrical power cleanliness limits
- Maximum takeoff temperature
- Maximum and minimum continuous temperature, current, voltage
- Vibration limits
- Any other information necessary for safe operation of the EPU

5.3.2 In determining the EPU performance and operating limitations, the overall limits of accuracy of the EPU control system and of the necessary information and parameters must be established.

5.3.3 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.

5.4 Materials

5.4.1 The materials and components used in the EPU must be established on the basis of industry or military ASTM(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 ASTM. 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 outside of a fire zone should be protected against arc-faults. Any non-protected electrical wiring interconnects within the fire zone should be analysed to show that arc faults do not cause a hazardous condition. If flammable materials are used or if arcing is probable in the EPU then the EPU will be in a fire zone and all fire zone protections must be employed.

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 in the Instructions for Continued Airworthiness as applicable.

5.7 EPU cooling

5.7.1 EPU cooling must be sufficient under all conditions within the declared operational limitations.

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 must 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:

(1) Failure of the cooling system would not lead to hazardous EPU effects before detection; or

(2) Other existing instrumentation or sensors provides adequate warning of failure or impending failure; or

(3) The probability of failure of the cooling system is extremely remote.

5.8 EPU mounting attachments and structure

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—

(1) The specified limit loads without permanent deformation; and

(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 fire proof.

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 effects.

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 IV or an equivalent standard.

5.9.2.1 Unless otherwise specified in IEC 60349, part IV, 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 ASTM rotor possesses the required overspeed capability. This can be accomplished by increasing test speed, temperature, and/or loads.

5.9.2.2 When a EPU test is being used to demonstrate compliance with the overspeed conditions listed in paragraph 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 minutes after the failure. Under these circumstances, the actual overspeed duration is acceptable if the required maximum overspeed is achieved.

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

5.9.3.1 120 percent of the maximum permissible rotor speed associated with any continuous, periodic or non-periodic duty rating, including ratings for short time duty.

5.9.3.2 115 percent of the maximum no load speed associated with any continuous, periodic or non-periodic duty rating, including ratings for short time duty.

5.9.3.3 105 percent of the highest rotor speed that would result from either:

5.9.3.3.1 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 and the associated no-load speeds or

5.9.3.3.2 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 5.2.4 of this section, when operating at any continuous, periodic or non-periodic duty rating, including ratings for short time duty and the associated no-load speeds.

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 paragraphs 5.9.3 of this section. The complete loss of load must also consider:

(1) demagnetization in combination with excessive external torque imposed (propeller induced no-load overspeed)

(2) failures external to the e-motor.

(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 paragraphs 5.9.5.1 and 5.9.5.2 of this section for the maximum overspeed achieved when subjected to the conditions specified in paragraphs 5.9.3 of this section. It must be established using the approach in paragraph 5.9.2 of this section that specifies the required test conditions.

5.9.5.1 Rotor Growth must not cause the motor operation to lead to a hazardous 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 motor EPU control systems, instruments, and other methods not covered under 5.10 must ensure that the motor 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 paragraph 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.

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 paragraph 5.2, any assumptions regarding the EPU installation in making the assessment described above in paragraph 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

5.10.1 The software and electronic hardware, including the complex electronic hardware and 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 manufacturers control, the assumptions with respect to the reliability and functionality of these parts must be clearly stated in the safety analysis (see section 5.18).

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:

5.10.3.1.1 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;

5.10.3.1.2 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;

5.10.3.1.3 Allows modulation of EPU power with adequate sensitivity over the declared range of EPU operating conditions; and

5.10.3.1.4 Does not create unacceptable power oscillations.

5.10.3.2 Environmental limits. Environmental limits that cannot be adequately substantiated in accordance with endurance testing must be demonstrated, via EPU system and component tests (see section 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, 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 non acceptable operating characteristics include but are not limited to:

- field excitation at rotor resonance frequency,
- electromagnetic lock –up (stall),
- unacceptable power changes or oscillations.
- other unacceptable characteristics, e.g. 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 (i.e., with no currently active faults), essentially single fault tolerant, as determined by the CAA, for electrical, electrically detectable and electronic failures with respect to LOPC events;

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

5.10.5.4 Not have foreseeable failures or malfunctions that lead to local events in the intended aircraft installation, such as arcing, fire, overheat, or other failures that result in the EPU control system's failure or malfunction.

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

5.10.7 Protection systems.

5.10.7.1 The design and functioning of 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 periods.

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

5.10.8.1 Not result in a hazardous EPU effect for any EPU; and

5.10.8.2 Be detected and accommodated. The accommodation strategy must not result in an unacceptable change in power or an unacceptable change in 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.

5.10.9 EPU control system electrical power

NOTE: 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 electrical power source will not result in any of the following:

5.10.9.1.1 A hazardous EPU effect, or

5.10.9.1.2 The unacceptable transmission of erroneous data, or

5.10.9.1.3 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 quickly enough to prevent any EPU hazard.

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 section 5.18) 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.

5.12 Vibration

5.12.1 The EPU must be designed and constructed to function throughout its normal operating range of rotor speeds and EPU output 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 aero-dynamic excitation, analysis of rotating component resonance induced by field-excitation, should also be assessed,

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 must be conducted to demonstrate that systems or components are able to perform the intended functions in all declared environmental and operating conditions.

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

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

5.14 Stress analysis

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

5.14.2 An electrical stress analysis must be performed on each EPU showing the electrical design safety margin of each electrical component above 220VAC 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, non-redundant 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 must 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, non-redundant 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 must be established by:

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

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

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

5.15.3. Requirements for life-limited parts. Operating limitations must be established by an approved procedure that specifies the maximum allowable number of flight cycles for 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 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. Manufacturers must 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 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.

5.15.4. 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 duct when operating at the maximum permissible speed. However, energy levels and trajectories of fragments resulting from a failed hub, rotor, or blade retention component that lie outside the duct must be defined.

5.16 Lubrication System

5.16.1 The lubrication system of the EPU must 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

5.17.1 If any of the EPU main rotating systems continue to rotate after the EPU is shutdown 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.

5.18 Safety analysis

5.18.1 The EPU design must be analyzed, including the control system, to assess the likely consequences of all failures that can reasonably be expected to occur. This analysis will include, if applicable:

5.18.1.1 Aircraft-level devices and procedures assumed to be associated with a typical installation. All assumptions must be stated in the analysis.

5.18.1.2 Secondary failures and latent failures that have EPU level consequences.

5.18.1.3 Multiple failures referred to in paragraph 5.18.4 of this section or that result in the hazardous EPU effects defined in paragraph 3.5of this section.

5.18.2 Failures that could result in major EPU effects or hazardous EPU effects, must be summarized with estimates of the probability of occurrence of those effects. These probabilities must be shown to be at least remote for major effects and at least extremely remote for hazardous effects. Any EPU part the failure of which could reasonably result in a hazardous EPU effect must be clearly identified in this summary.

5.18.3 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 must be identified as EPU critical parts. EPU critical parts should meet the prescribed integrity ASTMs of 5.16. These instances must be stated in the safety analysis.

5.18.4 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 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. Requirements for mitigation means, that are not part of the EPU, must be specified in the installation and operation instructions.

5.18.5 If the safety analysis includes one or more of the following items, those items must be identified in the analysis and substantiated.

5.18.5.1 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 must be published in the instructions for continued airworthiness and relevant manuals. Additionally, if errors in maintenance of the EPU, including the control system, could lead to hazardous EPU effects, the appropriate procedures must be included in the relevant EPU manuals.

5.18.5.2 Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details must be published in the appropriate manual.

5.18.5.3 The provisions of specific instrumentation not otherwise required.

5.18.5.4 Flight crew actions to be specified in the operating instructions.

5.18.6 Unless otherwise approved by the CAA and stated in the safety analysis, in accordance with this standard, the following failure definitions apply to the EPU:

5.18.6.1 An EPU failure in which the only consequence is partial or complete loss of power from the EPU will be regarded as a minor EPU effect.

5.18.6.2 An effect whose severity falls between those effects covered in paragraphs 5.18.6.1 and 5.18.6.2 of this section will be regarded as a major EPU effect.

5.19 Ingestion

NOTE: 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.

5.19.1 A cooling failure as the result of blocked cooling passages due to a bird strike up to 4 pounds or hail or ice contamination may be addressed via a design feature. In absence of a design feature to protect the cooling inlet, it must be shown that loss of cooling will not result in a hazardous EPU effect, or that blockage cannot lead to a cooling failure.

5.19.2 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 four pound 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.

5.19.3 The structural damage must not result in any of the effects listed in 5.18.6.2

5.19.4 Ingestion of objects into the inlet/EPU (that don't block the cooling passages) should not cause any of the problems listed in 5.19.1 through 5.19.3, nor should ingestion of an object into the inlet/EPU cause EPU damage that could result in hazardous EPU effector 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.

5.19.5 Water spray must not result in any of the effects listed in 5.18.6.2 throughout the EPU operating range. Spray must 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.

5.19.6 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.

5.20 Combination Tests

NOTE: EPU design and construction must minimize the development of an unsafe condition of the EPU between maintenance or overhaul periods defined in the Instructions for Continued Airworthiness as applicable.

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.

5.20.1 General conduct of EPU tests

5.20.1.1 In conducting a 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 must be subjected to a calibration check before powering on the endurance test.

5.20.1.2 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 must be subjected to any additional tests the CAA finds necessary.

5.20.1.3 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.

5.20.1.4 Upon conclusion of tests conducted to show compliance with this section, each EPU part or individual groups of components must meet the requirements of the teardown inspection (see 5.22). 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.

5.20.2 Endurance and durability test

5.20.2.1 An endurance and durability test of sufficient duration must show that the development of an unsafe condition is extremely remote between overhaul periods (or during the life of the EPU if no overhaul intervals are prescribed) and loss of power control is below 10^05/flight hour. 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 must be justified using validated analytical methods, empirical testing, or experience with EPU or motors with comparable design. During the endurance test the EPU power and the output shaft rotational speed must 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 must 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 must be run on an EPU representative of the type design. Any deviation to the type design must be recorded. It must be justified that any of the recorded deviations to the type design does not affect the results of the test.

5.20.2.2 The endurance and durability test must consist of at least the following elements:

5.20.2.2.1 A run consisting of alternate periods of operation at rated takeoff power and the minimum power and periods of operation at maximum continuous power and the minimum power, that can be commanded by the control system during operation.

5.20.2.2.1 A series of runs consisting of alternate periods of operation at maximum continuous power and successively lower power settings. The range of power settings should be selected to expose any deleterious system responses or vibration.

5.20.2.2.3 Each period of operation discussed in this section must 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 takeoff and maximum continuous ratings , the stabilized temperature for the motor and the motor controller must be equal to or greater than the temperature associated with this rating.

5.20.3 Vibration test

5.20.3.1 Each EPU must 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 must be established. This margin must be justified using analytical means, prior experience, or empirical data as applicable. The EPU test must 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.

5.20.3.2 The EPU test shall cover the ranges of 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 percent of the maximum rotational speed permitted for rating periods of two minutes or longer, and up to 100 percent 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.

5.20.3.3 Except as provided by paragraph 5.20.3.4 of this section, the vibration stresses associated with the vibration characteristics determined under this section, when combined with the appropriate steady state stresses, must 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 must 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 must be measured. The EPU must 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.

5.20.3.4 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 electro-magnetic 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.

5.20.3.5 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 section 5.2.

5.20.4 EPU overtorque test

5.20.4.1 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.

5.20.4.1.1 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.

5.20.4.1.2 Upon conclusion of tests conducted to show compliance with this section, each EPU part or individual groups of components must meet the requirements of the teardown inspection.

5.20.4.2.1 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.

5.20.4.2.2 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.

5.20.4.2.3 All EPU major components at maximum steady state temperature approved for use in compliance with the selected duty cycle(s) for type rating.

5.20.5 EPU over temperature test

5.20.5.1 Each EPU must be run at least for the time to reach steady state temperatures plus one hour of continuous operation at each of the rated conditions for any continuous, periodic or non-periodic duty rating, including ratings for short time duty.

5.20.5.2 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 must not violate the physical limitation of the permanent magnet material (curie-temperature) including sufficient safety margin. The safety margin must be justified.

5.20.5.3 Upon completion of all rating over temperature tests, the EPU including the rotor permanent magnets, if applicable, must be within serviceable limits.

5.20.6 Calibration tests

5.20.6.1 Each EPU must be subjected to those calibration 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.

5.20.6.2 A power check must be accomplished on the endurance and durability test EPU after the endurance and durability test described in this section and any change in power characteristics which occurs during the endurance and durability test must 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.

5.20.6.3 In showing compliance with this paragraph, each condition must stabilize before measurements are taken.

5.20.7 Operation test

5.20.7.1 The operation test must include testing to demonstrate:

5.20.7.1.1 Powering on, idling, acceleration, overspeeding, with loading representative of the intended installation;

5.20.7.1.2 Compliance with the EPU response requirements of paragraph 5.20.8.1;

5.20.7.1.3 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.

5.20.8 Power response

5.20.8.1 The design and construction of the EPU must enable an increase--

5.20.8.1.1 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

5.20.8.1.2 From the minimum obtainable 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 must occur from a stabilized condition.

5.21 Rotor locking tests

5.21.1 If continued rotation is prevented by a means to lock the rotor(s), the EPU must be subjected to a test that includes repeated operations to sufficiently establish reliable performance. The number of repeated unlocking operations must be justified or 25 cycles will be performed. This testing must be performed under the following conditions:

5.21.2 The EPU must be shut down from rated maximum continuous power; and

5.21.3 The means for stopping and locking the rotor(s) must 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

5.21.4 Following rotor locking, the rotor(s) must 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 must be justified.

5.22 Teardown Inspection

5.22.1 After completing the endurance test, the vibration test, the overtorque test, and the overtemperature test—

5.22.1.1 Each EPU must be completely disassembled;

5.22.1.2 Each EPU component having an adjustment setting and a functioning characteristic that can be established independent of installation on or in the EPU must retain each setting and functioning characteristic within the limits that were established and recorded at the beginning of the test; and

5.22.1.3 Each EPU component must conform to the type design and be eligible for incorporation into a EPU for continued operation, in accordance with information submitted in compliance with the instructions for continued airworthiness.

5.22.1.4 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 non-workable after tear down, alternative inspection can be proposed. There may be non-destructive tests for electrical systems. However, these alternative methods must capture the critical aspects intended for the inspection. Pre-measurements at build must be referenced at teardown.

5.22.1.5 If a teardown is not performed, then the life limit of the EPU will be established by the length of the endurance test performed.

5.23 Containment

5.23.1 Rotating part containment. The design of the cases that surround rotating components must provide for the containment of damage from failure of the rotating components. Fragments resulting from rotating component failure that escape containment must have their energy levels and trajectories defined by test or analysis.

5.24 EPU-variable pitch propeller or fan systems tests

5.24.1 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 must 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:

5.24.1.1 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.

5.24.1.2 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

5.24.1.3 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 must be operated in reverse pitch for a time interval sufficient to establish the reliability of the reverse pitch mechanism and must occur at the maximum rotational speed and power specified for reverse pitch operation. In absence of other justified time interval, a minimum of 30 seconds may be used.

2. BATTERY

Much discussion circulates around Lithium-metal batteries for their intrinsic characteristic of not being (as) flammable as current state-of-the-art industrialized battery cell solutions, which are Lithium based. MAHEPA believes that it is highly unlikely for Lithium-Metal batteries to be obtainable at reasonable cost and durability before 2023, therefore it is worthwhile determining certification paths for batteries made-up of COTS Lithium-Ion (and their derivatives) battery cells. DO-311(A) is the de-facto standard for Airborne Lithium Batteries, and while Revision A brings a promising alternative compliance demonstration procedures with its appendix C, it has not yet been adopted. Also, it is lacking the important consideration of where the battery would be physically installed on the aircraft – i.e. zoning considerations. MAHEPA proposal for future battery certification options and AMC is twofold:

a) Class 2-4 of CS-23 aircraft (typically 4-19 seats)

b) Class 1 of CS-23 aircraft (typically 2-3 seats)

Note: In an effort to synchronise with aviation terminology adopted by ASTM F44.91, the battery is referred to as an Energy Storage System (ESS).

A)

1 Intent

1.1 This set of requirements defines a minimum set of acceptable safety design and testing criteria for high capacity rechargeable Energy Storage Systems (ESS) to provide power for aircraft propulsion.

1.2 Units—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of th e other. Combining values from the two systems may result in nonconformance with the standard.

2 Referenced Documents

2.1. RTCA DO-311A "Minimum Operational Performance Standards for Rechargeable Lithium Battery Systems"

2.2. SAE J2929 "Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells".

2.3. RTCA DO-160 "Environmental Conditions and Test Procedures for Airborne Equipment"

2.4. SAE J1739 "Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA)"

2.5. ASTM F3005 "Standard ASTM for Batteries for Use in Small Unmanned Systems"

3 Terminology

3.1 Battery—A device composed of electrochemical cells used to convert chemical energy to electrical energy

3.2 Battery cell rupture – Loss of mechanical integrity of the cell housing, resulting in release of contents. The kinetic energy of released material is not sufficient to cause physical damage external to the battery system

3.3 Battery enclosure rupture – Openings through the battery enclosure which are rapidly created or enlarged by an event and which are sufficiently large for a 50 mm diameter sphere to contact battery system internal components (see ISO20653, IPXXA).

3.4 Battery Management System – The hardware and software used to monitor the state of the cells comprising the battery and to regulate rates of charge and discharge.

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

3.6 C – maximum steady-state current (amps) at which the battery cell or pack may be discharged without having pack temperature exceed the CTT of its constituent cell(s) or result in a reduction in cell life. C-rating is expressed as a multiple of the cell or pack capacity.

3.7 Cell – The smallest electrochemical unit, consisting of two electrodes, current collectors, separator, electrolyte, and all associated packaging.

3.8 Cmax – Maximum allowable discharge rate

3.9 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.

3.10 Electrical isolation - The electrical resistance between the vehicle high-voltage system and any vehicle conductive structure.

3.11 Energy Storage System (ESS)—A complete energy storage device consisting of one or more energy storage cells arranged into one or more packs, with ancillary subsystems for physical support and enclosure, thermal management, and electronic control. Typical energy storage cells include but are not limited to batteries or capacitors

3.12 Fire – The emission of flames from a battery for more than 5 seconds. Sparks are not flames.

3.13 kWh - Kilowatt hours, a measure of the total electrical potential energy

3.14 Minimum Voltage – lower voltage limit at which discharge current is discontinued.

3.15 Pack – A single cell or composition of battery cells connected in series or in parallel or any combination thereof and associated monitoring electronics, structure, and connector(s). Also addressed to as a “module”.

3.16 SOC – State of Charge, fraction of maximum rated capacity retained by a cell or pack at a given time, from 0 to 100%

3.17 Thermal runaway – A rapid self-sustained heating of a battery cell driven by exothermic chemical reactions of materials within the cell.

3.18 Venting – The release of excessive internal pressure from a cell, or pack in a manner intended by design to preclude rupture or explosion.

4 Significance and use

4.1 Purpose – This ASTM provides design, testing and installation guidance for manufacturers of Energy Storage Systems (ESS) for aircraft propulsion including criteria to use in designing an ESS with the intent of gaining approval from a civil aviation authority.

4.2 The ideal outcome of this set of requirements is to assure that an ESS can safely be integrated into an aircraft such that any single point fault will not result in fire, explosion, or high voltage hazard. This document includes tests that simulate “normal” conditions and “off-normal” conditions that, although infrequent, may occur during service life. Pass/fail criteria are assigned to each test.

4.3 This document discusses ESS used to power aircraft propulsion which are typically of high capacity in contrast to batteries for secondary systems or auxiliary power.

5 Marking

5.1 Manufacturer's marking and labeling - The ESS exterior shall contain the following minimum information in a legible and durable form:

5.1.1 Manufacturer's name or CAGE code

5.1.2 Manufacturer's model or part number

5.1.3 Manufacturer’s serial number and/or date of manufacture –

5.1.4 Electrical connection polarity unless a keyed connector is used

5.2 The manufacturer's marking and labeling on the ESS exterior shall also contain the following information in a legible and durable form. If there is not adequate space on the battery, the information shall be included in the documentation:

5.2.1 Maximum rated energy in kWh

5.2.2 Nominal rated capacity (Ah and/or kWh) at specified discharge rate

5.2.3 Nominal battery or battery system voltage

5.3 Safety (high voltage) labeling – [import from SAE / DO311]

6 Data requirements

6.1 Manufacturer Retained Data—The following data and information shall be retained on file at the manufacturer’s facility or alternative business entity for a minimum time set by an Aviation Authority after production is discontinued.

6.1.1 Drawings, reference ASTMs, and other technical data that define the ESS configuration

6.1.2 Engineering analyses and test data prepared for qualification with this ASTM

6.2 Delivered Data—The following data shall be provided by the manufacturer of the ESS:

6.2.1 Ratings and limitations – Manufacturer shall provide all applicable ratings and limitations to which the ESS has been tested, including maximum capacity, discharge rate, maximum and minimum voltage, and the related environmental conditions.

6.2.2 Thermal loads – Maximum temperatures for the ESS in normal operation shall be provided

6.2.3 Structural mounting loads – Maximum acceptable loads at ESS mount points shall be provided.

6.2.4 Instructions for installation and operation – Detailed instructions for the installation, operation, and removal of the ESS shall be provided.

6.2.5 Instructions for continued airworthiness – Description of ongoing maintenance and test procedures and schedules ensuring continued airworthiness of the ESS shall be provided.

6.2.6 Performance under applicable operating conditions and environments – Manufacturer shall provide an approved operating environment for which the ESS has completed testing under this standard.

6.2.7 Interface control document - Manufacturer shall provide a detailed description of the electrical and software interface requirements for proper communication with and control of the ESS and related subsystems, including the Battery Management System. This document shall include all possible inputs to and all potential outputs from the ESS and related subsystems as well as required communication protocols.

7 Design criteria

7.1 Fire protection: All materials used should not contribute significantly to the propagation of a fire. Internal and external materials of the battery and battery system are required to meet the applicable certification flammability requirements of the installation.

7.2 Battery protective features: The battery system shall have protective features to prevent unsafe conditions during operation.

7.2.1 Protective circuits, including the battery disconnect function, should be suitably protected from cell failure conditions within the battery such that the safety function is not compromised.

7.3 Battery warning features: The battery system should include monitors to detect battery fault conditions (including over-temperature and overvoltage) and provide appropriate warning signals.

7.3.1 Warning circuits should be suitably protected from cell failure conditions within the battery system such that the warning signal is not compromised.

7.4 Overdischarge Protection: If the battery chemistry in use is subject to damage in an over-discharge situation, the battery system shall have a means to identify the condition and prevent charging until the battery can be inspected and returned to service.

7.5 State of health: The battery system shall have a means to communicate the current state of charge, voltage, and any other parameters specified by the manufacturer necessary to determine state of health.

7.6 Built-In Test: The battery system should include a built-in-test function, with the ability to report detected malfunctions or abnormal conditions.

7.7 Venting provisions: The battery system shall not emit any flammable, toxic or corrosive gases, smoke, soot particulates or fluids during normal operation.

7.7.1 In case of one or more battery cell failures, the ESS shall include provisions to safely relieve the maximum pressure that can occur when tested in accordance with this standard.

7.8 Design guidelines: A set of guidelines for battery mechanical and electrical design and construction can be found in Reference 2.1, section 2.1.10

8 Performance

8.1 Acceptance Test Procedure: The manufacturer of the ESS is responsible for providing an acceptance test procedure (ATP) which is sufficient to verify that the system meets or exceeds the minimum rated performance.

8.1.1 The ATP shall be of sufficient scope to test all system circuit paths and modes of operation required to meet specified performance and functional requirements.

8.2 Rated capacity: Rated Capacity shall be specified by the manufacturer as determined in section 10.5

8.3 Environmental performance: The ESS manufacturer shall provide performance including capacity, current, and voltage for charge and discharge at the maximum and minimum allowable operating temperatures.

8.4 Rate of discharge: The manufacturer shall establish and provide a maximum allowable discharge rate.

9 Safety requirements

9.1 Categories of ESS integration – Three categories of ESS are defined based on airframe integration; the minimum safety criteria vary according to category:

A) ESS located within the primary pressure vessel, or, for an unpressurized aircraft, within, or immediately adjacent to the cabin such that gases vented by the ESS could enter the passenger compartment.

B) ESS isolated from occupants but in proximity to aircraft primary structure, for example in a wing bay similar to a conventional fuel tank.

C) ESS isolated from occupants and primary structure, e.g. behind a firewall or in an external capsule.

9.2 Containment following failure: The ESS shall comply with the following requirements following any failure within the system, including cell level failures:

9.2.1 Category A:

9.2.1.1 No release of fragments outside of the battery system.

9.2.1.2 No escape of flames outside of the battery system.

9.2.1.3 No damage to primary airplane structure from rupture

9.2.1.4 Emissions shall be exhausted external to the aircraft; consideration shall be given to preventing the buildup of flammable gases.

9.2.1.5 No potential for inadvertent high voltage exposure; high voltage to ground isolation maintained at no less than 100 Ω/V

9.2.2 Category B:

9.2.2.1 No release of high energy fragments outside of the battery system

9.2.2.2 No escape of flames outside of the battery system.

9.2.2.3 No damage to primary airplane structure from rupture

9.2.2.4 Emissions: consideration shall be given to preventing the buildup of flammable gases.

9.2.2.5 High voltage to ground isolation maintained at no less than 100 Ω/V

9.2.3 Category C:

9.2.3.1 No release of high energy fragments outside of the battery system

9.2.3.2 No escape of flames outside of the battery system.

9.2.3.3 No damage to primary airplane structure from rupture

9.2.3.4 Emissions: consideration shall be given to preventing the buildup of flammable gases.

9.2.3.5 High voltage to ground isolation maintained at no less than 100 Ω/V

9.3 Electrical shock: The design shall incorporate electrical isolation-insulation materials capable of protecting aircraft occupants and ground personnel from electrical shock in the event of an inflight or ground based emergency.

9.4 Crashworthiness and immersion: In case of an accident, a functionally intact ESS shall not provide undue shock and fire hazard to occupants and rescuers, including when immersed in water.

10 Testing and qualification requirements

10.1 General requirements

10.1.1 The complete Energy Storage System is to be tested.

10.1.2 Except where specifically noted to the contrary, the state of charge (SOC) shall be at 95-100% of the maximum which is possible during normal vehicle operation and temperature shall be 25 °C ± 5 °C prior to initiation of the test. If the responsible organization is aware that a different temperature within the normal operating temperature range of the system may represent a more severe condition, the responsible organization shall alternatively specify this temperature.

10.1.3 The test setup for the ESS shall be representative of the intended aircraft installation including venting, cooling, grounding, and mounting provisions.

10.1.4 All data necessary for assessing conformance to the requirements included in this Standard shall be collected. Video recording shall be used for any tests which include possibility of battery cell failure.

10.1.5 Test safety: Many of the tests and conditions may result in hazardous conditions both during the test and with the test article following the test. Hazards include sparks, fire, electrical shock, explosive cell rupture, and release of hazardous gases including carbon monoxide (CO) and hydrogen fluorine gas (HF). Proper care should be taken to protect personnel and property during the test and afterwards.

10.2 Conditions of test: The following conditions for test equipment and conditions shall apply to all testing

10.2.1 Testing is to be conducted at standard day conditions unless otherwise specified: Air pressure 84 kPa to 107 kPa (equivalent to +5000 to -1500 ft pressure altitude), Ambient Temperature: 23 ± 5°C, and relative humidity less than 85%. The chosen test conditions should represent reasonable worst case conditions to be encountered by the ESS under operation.

10.2.2 Temperature stabilization is defined as the temperature of a cell at the center of the ESS being within 3°C of target for at least one hour.

10.2.3 Measuring Apparatus – The measuring method used for the tests shall be selected to suit the magnitude of the parameters to be measured. All test and measurement where appropriate. The measurement equipment shall be calibrated to the equipment manufacturer's ASTMs.

10.2.4 Current and Voltage Measurement – The current and voltage measurement shall have a minimum accuracy of 0.5%, unless otherwise stated.

10.2.5 Temperature Measurement – The temperature measurement shall have a minimum accuracy of 1°C unless otherwise stated.

10.3 Testing guidelines: A best practices set of test guidelines for an ESS containing Lithium Battery cells is provided in section 2.4.2 of Reference 2.1

10.4 Environmental testing: The ESS shall be tested for each operating environment in which it is approved for use. Guidance on environmental test procedures may be found in Reference 2.3; additional guidance may be found in Reference 2.2.

10.4.1 Tests may include, but are not limited to: thermal shock; humidity / moisture exposure; maximum and minimum operating temperatures, air pressure, sand and dust, salt fog, power input, voltage spike, induced signal susceptibility, RF susceptibility, lightening induced transient, lightening direct effects, icing, electrostatic discharge, and electromagnetic susceptibility. The subset of tests are chosen depending on installation/operating criteria of the ESS to be approved.

10.4.2 For each test, the ESS shall be operating in the mode, or modes, most likely to exhibit adverse effects due to the environmental conditions, including peak charge and discharge rates.

10.4.3 Thermal regulation (heating and/or cooling), and other environmental control measures built into the ESS shall be active during the test. For battery heating or cooling, the thermal regulation may begin no more than 15 minutes prior to start of the test, and after temperatures have stabilized.

10.4.4 Any fire prevention systems built into the ESS shall be active during the test.

10.4.5 Test requirements: During the test and for a minimum 1 hour post-test observation period, the battery system shall comply with the safety requirements in section 9 of this standard. In the event that a gas concentration measuring device is used, flammable gas concentration shall not exceed the lower flammability limit in air.

10.5 Capacity test: The manufacturer is responsible for testing the ESS at temperatures and discharge rates representative of the intended usage, which may include time dependent rate profiles. For each rate, or rate profile, and temperature tested, the following test procedure shall be used:

10.5.1 The ESS should be fully charged with temperature stabilized as defined in section 10.2.2 of this standard.

10.5.2 Discharge shall continue until reaching manufacturer specified minimum voltage.

10.5.3 Discharge voltage, current, time, and total power shall be recorded.

10.6 Charge acceptance: The ESS shall be tested to determine time to fully charge from a minimum voltage state at standard operating and lower limit operating temperatures, up to the maximum allowable charging rate.

10.6.1 Cell heaters may be used in the low temperature test if installed.

10.6.2 Reference 2.1, section 2.4.4.8 may be used for guidance on charge acceptance testing.

10.7 Maximum discharge rate at high temperature – From a fully charged state and stabilized at the manufacturer specified high temperature operating limit, the ESS shall be fully discharged at Cmax to minimum voltage by the following method:

10.7.1 With ESS at a fully charged state, the temperature is stabilized to upper limit as defined in section 10.2.2 of this standard.

10.7.2 ESS discharged at Cmax to minimum voltage. Cell cooling system may be used if installed.

10.7.3 Record the external temperature of the ESS during the test and for an additional 1 hour after discharge is complete.

10.7.4 Record the internal temperature of one or more cells

10.7.5 All standard protective circuits are functional which may limit discharge rates to prevent cell over-temperature conditions.

10.8 Short circuit test with protection enabled –Test is conducted to show the effectiveness of the protective circuitry when the battery or battery system is subjected to a short circuit condition. Test method:

10.8.1 ESS is fully charged and all internal or external protective circuits are fully operational

10.8.2 All external power sources are disconnected

10.8.3 A short circuit shall be applied to the terminals of the ESS, with a total resistance not to exceed 0.1 Ohms.

10.8.4 Continue to apply the short circuit for a minimum of 30 minutes, recording voltage and temperature

10.8.5 Test requirements: During the test and for a minimum 1 hour post-test observation period, the battery system shall comply with the safety requirements in section 9 of this standard. In the event that a gas concentration measuring device is used, flammable gas concentration shall not exceed the lower flammability limit in air.

10.8.6 Safety warning – Test poses safety hazard due to possibility of fire and explosion.

10.9 Single point overdischarge protection failure; charge test with protection enabled – simulates the condition in which a battery is allowed to discharge beyond the lower voltage limit, at which point internal damage may occur causing hazard on subsequent charging. This test is conducted to show the effectiveness of the charge inhibit circuitry when a recharge is attempted after the battery or battery system has been subjected to an overdischarge condition. Test method:

10.9.1 Disable or bypass any discharge protection as necessary to obtain an over discharged condition. Do not disable any charge inhibit protection designed to prevent charging after an overdischarge. Protective devices that are incorporated within the cell(s) shall not be disabled.

10.9.2 Discharge ESS to minimum voltage at standard discharge rate

10.9.3 With the ESS at ambient temperature, apply a 1 Ohm resistor (or the minimum resistance needed to prevent overcurrent tripping) to the terminals and continue discharging until voltage is below 5% of minimum voltage.

10.9.4 Apply a charge to the ESS in accordance with the manufacturer's instructions.

10.9.5 Monitor the ESS for a sufficient period of time to allow charge inhibit protection.

10.9.6 Test requirements: During the test and for a minimum 1 hour post-test observation period, the battery system shall comply with the safety requirements in section 9 of this standard. In the event that a gas concentration measuring device is used, flammable gas concentration shall not exceed the lower flammability limit in air.

10.9.7 Safety warning – test poses safety hazard due to possibility of fire and explosion.

10.10 Overcharge test with protection enabled – Test is conducted to show effectiveness of the protective circuitry of the ESS when overcharged at 1.5x the rated nominal voltage or the maximum bus charging voltage, whichever is higher. Overcharge protective circuitry shall prevent the battery cells from being exposed to an overcharge condition which could lead to thermal runaway. Test method:

10.10.1 ESS shall be fully charged with all protective circuitry fully operational.

10.10.2 Initiate charging from a power supply at 1.5 times the rated nominal battery voltage

10.10.3 Charge the battery system at the maximum possible charge rate for the application, up to 1.5x the rated nominal charge voltage. (If passive over-current circuit protection is below this current, conduct test at maximum current compatible with passive protection device.) Maximum voltage shall be limited to charging device output limit. Continue charging until the charge device voltage is reached or the connection interface disconnects battery from charge device.

10.10.4 The power supply should be removed after 1 hour or if disconnected automatically by the ESS.

10.10.5 To assess the presence of flammable gas in suffi cient quantity to ignite, a spark source (at least 2 sparks/sec with sufficient energy to ignite natural gas) or gas concentration measuring device is required at a minimum of one location. Location is to be selected to represent the location of highest potential for gas leaks, as determined by the responsible organization. If a spark source or gas concentration measuring device is not used, post-test visual inspection of all cells must show no cell venting.

10.10.6 Voltage shall be recorded at the external charging point, and at an internal point behind the protective circuitry

10.10.7 Test requirements: During the test and for a minimum 1 hour post-test observation period, the battery system shall comply with the safety requirements in section 9 of this standard. In the event that a gas concentration measuring device is used, flammable gas concentration shall not exceed the lower flammability limit in air.

10.10.8 Safety warning – test poses safety hazard due to possibility of fire and explosion.

10.11 Single Point Overcharge Protection System Failure – simulates the condition where the battery system charge device is no longer being controlled and the failure may allow the battery system to be overcharged. Test method:

10.11.1 With the ESS fully charged, disable the active charge control function. Integrated, passive circuit protection devices are operational.

10.11.2 Cooling system should be operating, if it normally would be operating for all charging conditions.

10.11.3 Charge the battery system at the maximum possible charge rate for the application. (If passive over-current circuit protection is below this current, conduct test at maximum current compatible with passive protection device.) Maximum voltage shall be limited to charging device output limit. Continue charging until the charge device voltage is reached or the connection interface disconnects battery from charge device.

10.11.4 To assess the presence of flammable gas in sufficient quantity to ignite, a spark source (at least 2 sparks/sec with sufficient energy to ignite natural gas) or gas concentration measuring device is required at a minimum of one location. Location is to be selected to represent the location of highest potential for gas leaks, as determined by the responsible organization. If a spark source or gas concentration measuring device is not used, post-test visual inspection of all cells must show no cell venting.

10.11.5 Test requirements: During the test and for a minimum 1 hour post-test observation period, the battery system shall comply with the safety requirements in section 9 of this standard. In the event that a gas concentration measuring device is used, flammable gas concentration shall not exceed the lower flammability limit in air.

10.12 Single point thermal control system failure –This condition simulates the condition where the battery system temperature control is no longer operating and the failure may lead to a battery system over temperature condition.

10.12.1 This test is only required if the ESS has an active thermal control system.

10.12.2 With the active thermal control system disabled and the battery in a fully charged state, initiate one full cycle of maximum rate discharge followed by maximum rate charge.

10.12.3 All other system protection circuitry is to remain active and inhibit rates of charge and discharge as designed.

10.12.4 Test requirements: During the test and for a minimum 1 hour post-test observation period, the battery system shall comply with the relevant safety requirements in section 9 of this standard. In the event that a gas concentration measuring device is used, flammable gas concentration shall not exceed the lower flammability limit in air.

10.13 Protection against high voltage exposure – This test verifies that the battery system is electrically disconnected from the vehicle high voltage system when commanded to do so.

10.13.1 Manual disconnect - Provide a method for manually removing any voltage between its positive and negative output terminals when assessed without connection to the remainder of the vehicle high voltage system. Measured voltage across all external battery terminal sets shall be less than 60 VDC within 5 s after the manual disconnect is actuated with the automatic disconnect (for example, contactors) closed.

10.13.2 Automatic disconnect - At least one of the external terminals of the battery system shall be electrically disconnected from the battery cells within 5 s after actuation of the battery system automatic disconnect.

10.14 Drop test: This condition simulates a service condition where the ESS is removed (or being removed) from the vehicle and is dropped to the tarmac while separate from the vehicle.

10.14.1 Drop surface shall be representative of tarmac; e.g. concrete slab or asphalt.

10.14.2 ESS shall be fully charged and at standard temperature

10.14.3 Drop height is 20 cm (7.87 in)

10.14.4 The battery system shall be oriented in such a way to represent the most likely impact orientation based on battery system size, shape, installation location and usage. The responsible organization shall develop and document the rationale for the selected orientation.

10.14.5 Test requirements: During the drop test and for a minimum 1 hour post-drop observation period, the battery system shall exhibit no evidence of fire, or explosion.

10.15 Vibration – The ESS shall be tested with a vibration spectrum appropriate to the vehicle's operation. Reference 2.3 includes vibration testing guidance for air vehicles.

10.15.1 Test requirements: During the test and for a minimum 1 hour post-test observation period, the battery system shall comply with the relevant safety requirements in section 9 of this standard. In the event that a gas concentration measuring device is used, flammable gas concentration shall not exceed the lower flammability limit in air.

10.15.2 Post-test pack open circuit voltage shall be no less than 90% of the pre-test pack open circuit voltage.

10.15.3 Post-test visual inspection of battery system internal components shall identify no evidence, as a result of the test, of cracked, damaged or loosened high voltage conductors which are part of the primary power current path.

11 Fault Analysis

11.1 A fault analysis of the system design shall be conducted to show that plausible single point faults will not result in violation of the safety requirements defined in section 9.

11.2 Analysis shall include the full ESS consisting of the battery, enclosure, cooling system, electrical conducting system, connection interface, battery control function, charge/discharge control function, charge device, and discharge load

11.3 Analysis should be conducted according to a defined and documented analysis method; acceptable methods include SAE J1739, AC 23-1309, and ARP4754.

11.4 Analysis should include the following partial list of fault conditions; additional fault conditions, appropriate to the battery system design, shall also be included as determined by the responsible organization.

11.4.1 Battery cell internal failures (including those which result in cell thermal runaway)

11.4.2 Failures in the charge control system

11.4.3 Failures in the discharge control system

11.4.4 Failures in the temperature control system

11.5 Completed and documented fault analysis by the responsible organization, including closure of all identified action items, showing that plausible single point faults will not result in fire external to the battery enclosure, explosion of the battery enclosure, battery enclosure rupture or high voltage hazard.

3. INTEGRATION – HYBRID/ELECTRIC AIRCRAFT-LEVEL TYPE CERTIFICATION

In the spirit of future ASTM standards, the numbering on the following sectons is followoing the expected section numbering in these standards.

4. Powerplant Installation

4.1 General

Each powerplant installation shall meet the applicable requirements of ASTM F3062.

Each propeller system shall meet the applicable requirements of ASTM F3065.

Each EPU shall meet the technical requirements of an accepted standard appropriate to the application.

5. Energy Distribution Systems

5.1 General

5.1.1. Each energy distribution system shall meet the applicable requirements of ASTM F3063 and F3316/3316M.

5.1.2. Each energy distribution system shall safely provide sufficient power to each EPU under the most critical operating conditions.

5.1.3. The combined usable energy capacity of all energy storage systems shall be enough to maintain maximum continuous power of the EPU for a minimum of 30 minutes. For hybrid systems this may be accomplished with any combination of generation and energy storage.

Note: Operational rules for which the aeroplane is intended to be used may require greater endurance.

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.

5.3 Energy Storage System

5.3.1.1. Each energy storage system shall be installed in accordance with the applicable installation instructions.

5.3.1.2. Each energy storage system shall be designed to safely deliver the required power under the conditions specified in section 5.1.2 when drawn upon.

5.3.2. Installation

5.3.2.1. Each energy storage system shall be supported to withstand the vibration and inertia loads to which it may be subjected in operation.

5.3.2.2. Each energy storage system shall have access provisions for maintenance.

5.3.2.3. Design precautions shall be taken to minimize the hazards to the aircraft in the event of a fire or sudden discharge which could result in damage to components, structure, or flight controls near the storage area.

5.3.2.4. The energy storage system installation shall protect the occupants and the critical airframe and systems from a single cell thermal runaway.

5.3.3. Compartments

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 section 5.3.3.2 shall sustain any personnel compartment pressurization loads without permanent deformation or failure under the conditions defined in ASTMs 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.

5.3.4. Energy Capacity

5.3.4.1. The usable energy capacity for each energy storage system shall be established.

5.3.4.2. The available remaining energy quantity information shall be provided.

5.3.5. Charging System

5.3.5.1. The charging connection and system shall be designed to minimize the hazards to personnel.

5.3.5.2. The charging connection shall be designed to ensure correct connection of the charging connector.

5.3.5.3. The charging system shall be designed to protect the aeroplane from a charging source with incorrect voltage including high voltage, low voltage, incorrect polarity, effects of shorting, and type of current (AC/DC).

5.3.6. Pilot-replaceable energy storage systems

5.3.6.1. Each energy storage system location where electrical components can be replaced shall be marked.

5.3.6.2. Design precautions shall be taken to prevent incorrect installation of components when replaced in operation.

6. Control and Indication

6.1 General

6.1.1. Each powerplant installation shall meet the applicable requirements of ASTM F3064.

6.1.2. For any energy storage system that should not be depleted in normal operation, there shall be a separate indication to the flight crew when less than approximately 30 minutes of usable energy quantity or 50 percent of the usable energy capacity remains in the energy storage system, whichever is less.

6.2 Controls

6.2.1. There shall be a means to provide separate power control for each EPU, unless it can be shown that multiple EPUs operated by a single control will not prevent the isolation of a failed unit, and the control of the remaining units to ensure continued, safe flight and landing.

6.2.2. Shutoff Controls:

6.2.2.1. There shall be an independent, simple, and reliable means to disconnect each energy storage system.

6.2.2.2. If the EPU or energy storage system is installed in a fire zone, there shall be a means to allow appropriate flight crew members to rapidly shut off, in flight, the energy supply to the EPUs and energy storage system individually.

6.2.2.3. No shutoff means may be on the fire zone side of any firewall.

6.2.2.4. There shall be a means to guard against inadvertent operation of each shutoff means.

6.2.2.5. There shall be a means to allow appropriate flight crew members to reopen the shutoff means rapidly after it has been closed.

6.3 Powerplant Operational Characteristics and Installation

6.3.1. General

6.3.1.1. Electric Propulsion Systems shall have no adverse characteristics during normal or emergency operation within the operating limitations. This investigation shall consider the results of inadvertent energy storage system overcharging and/or limited energy dumping capability during propeller windmilling and reversing operation.

6.3.2. Cooling Test Requirements

6.3.2.1. For showing compliance with the general cooling test requirements of ASTM F3064 the aeroplane shall be flown in the configurations, at the speeds, and following the procedures recommended in the Aeroplane Flight Manual that correspond to the applicable performance requirements that are critical to cooling.

6.3.3. Starting and Stopping

6.3.3.1. The design of the installation shall be such that risk of fire or mechanical damage to the EPU or the aeroplane, because of starting the EPU in any conditions in which starting is to be permitted, is reduced to a minimum. Any techniques and associated limitations shall be established and included in the Aeroplane Flight Manual, approved manual material, or applicable operating placards.

6.3.3.2. There shall be a means for stopping the rotation of any EPU or component, if continued rotation would cause a hazard to the aeroplane.

6.3.3.3. If hydraulic propeller feathering systems are used for stopping the EPU, the hydraulic feathering lines or hoses shall be fire resistant under the operating conditions expected during feathering.

6.3.3.4. Restart Envelope—An altitude and airspeed envelope shall be established for the aeroplane for inflight engine restarting and each installed EPU shall have a restart capability within that envelope.

6.3.3.5. Restart Capability—No unsafe condition may arise from re-engaging any EPU after a shutdown either on ground or in flight.

6.3.4. Powerplant Limitations

6.3.4.1. The powerplant limitations shall be established so that they do not exceed the corresponding limits of the EPU, the energy storage system and associated equipment.

7. Hazard mitigation

7.1 General

7.1.1. Each powerplant installation shall meet the applicable requirements of ASTM F3066.

7.1.1.1. For compliance with the engine isolation requirements of ASTM F3066 "an energy storage system, if only one energy storage system is installed" is considered "a fuel tank, if only one fuel tank is installed".

7.3 Fire Protection

7.3.1. Designated Fire Zones

7.3.1.1. The EPU or ESS section is a designated fire zone, if a fire hazard exists.

7.3.2. Fire Detection

7.3.2.1. There shall be means that ensure the prompt detection of a fire in each fire zone that is not visible to the crew.

7.3.3. Lightning Protection

7.3.3.1. For level 1 aircraft intended for night VFR and IFR operation and for level 2 or higher aircraft, each energy storage system shall be designed and arranged to prevent the ignition of flammable vapor or contents within the system by corona or streamering at vent outlets and ESS areas.

7.4 Ice Protection

7.4.1. Each air inlet of the powerplant installation shall be protected from ice accumulation, when operated in the conditions for which it is to be certified as defined in ASTM F3120/F3120M.

4. ENABLING PRINCIPLES FOR FUTURE CERTIFICATION PATHS

4.1. COTS FOR COMPLEX ELECTRONIC HARDWARE

Using COTS equipment, in particulary microchips and other similar electronic components or assemblies, may unlock significant gains in cost competitiveness as well as safety gains related to new architectures enabled by use or much cheaper components.

EASA has already initiated work for using COTS for CS-25 as an alternative to DO-254 (EASA Certification Memorandum EASA CM No.: EASA CM - SWCEH – 001 for Development Assurance for Airborne Electronic Hardware – for CS-25 as an alternative to DO-254, EASA CRI F01: Installation of DAL D COTS equipment), however the real gains may arise from the new basic regulation and CS-DRONE specifications.

Related in particular to power control (power electronics, torque delivery command and power-by-wire) functionality, approving the use of COTS would clear the path to using highest quality power chips (IGBTs, SICs), for which the handful of global manufacturers will never release design data, in order to protect their business secrets.

(EASA Certification Memorandum EASA CM No.: EASA CM - SWCEH – 001 for Development Assurance for Airborne Electronic Hardware – for CS-25 as an alternative to DO-254)

(EASA CRI F01: Installation of DAL D COTS equipment)

4.2. CONCEPT OF NET-SAFETY-BENEFIT

The cost to develop and certify safety enhancing systems can often place the cost of the equipment out of reach of the small airplanes that would most benefit from their installation. This section proposes a method by which an applicant can assess the safety benefit afforded by the system against the risks associated with the system failure / malfunction to justify a reduction in the level of certitude required. In order to justify the reduction in certitude, the safety benefits of the system across all target aircraft should clearly offset the risk of failure/malfunction on individual airplanes.

While this mentality is being developed with systems in mind, there may be other safety enhancing design elements for aircraft that could use this process to justify an appropriate reduction in the level of certitude based on a clear net safety benefit. As an example - with lack of data to substantiate reliability figures, the concept of net-safety-benefit could be used instead.

To perform this assessment, the following steps must be completed dilligently

1) Assess the safety benefits afforded by the system
2) Assess the potential risks introduced by installing the system
3) Score the safety benefits against the risks
4) Propose the desired reduction in certitude or the alternate means of compliance

Procedure:

1 Assess the Safety Benefits Afforded by the System

1.1 An assessment must be performed and documented that identifies the potential overall safety benefits provided by the installation of the system. This may be either a qualitative assessment or a quantitative assessment depending on the information available and how obvious the safety benefits are.

2 Assess the Potential Risks Introduced by Installing the System

2.1 The system safety requirements of ASTM F3061 require that an assessment be performed that identifies and classifies the failure conditions introduced or affected by the installation of the system. The applicant should use this assessment to document the risks presented by the installation of the system. There should be particular emphasis on assessing possible means to mitigate potential failures that may be available to the pilot.

3 Score the Safety Benefits Against the Risks

3.1 The overall improvement of safety must be weighed against the risks of potential failures. This may be a qualitative or quantitative analysis.

3.2 The depth of analysis required to justify the net safety benefit will depend heavily on how obvious the safety benefits are and how they compare to the risks.

4 Propose the Desired Reduction in Certitude or Use of an Alternate Means of Compliance

4.1 The applicant should produce a report that documents the results of the above assessments in a manner that is acceptable to the Civil Aviation Authority.

4.2 Within that report, the applicant should propose the desired reduction in the level of certitude or the use of an alternate means of compliance, such as system verification in accordance with ASTM F3153.

4.3 The applicant should justify the appropriateness of the proposal. Consideration must be given to any additional risks associated with the reduction in certitude or the use of an alternate means of compliance and any mitigations that they propose using to address those additional risks.

CONCLUSION

Development of standards for future aplication is a complex task, typically with a 5-8 year horizon in activity before a proposed language is approved by the authorities and released into practice. MAPEHA prototypes with their demonstrations will serve as a tool to validate proposed certification basis (potential future standards) basis by trialing and proving technical requirements and envisioned means of implementation for core components of hybrid electric powertrains for CS-23 category of aeroplanes.

There are, of course, future challenges to be addressed. This is particularly connected to streamlining certification of complex electronic hardware, use of COTS equipment and software. We urge the regulators and readers to consider the enablers of future means of flying, which relay heavily on affodable, yet reliable electronic hardware and software implementation. This is what will truly power the aircraft of the future.

APPENDIX

Appendix 1: Terminology structure