



AEROSPACE INFORMATION REPORT

AIR7128™

Issued

2026-04

Integration and Certification Considerations for Electrified Propulsion Aircraft

RATIONALE

The novelties introduced by the electrification of propulsion may have an impact on the traditional compliance demonstration activities at engine level and on the integration of the powerplant system in the aircraft. The need to provide to the manufacturers that incorporate this new technology the tools to certify their products has caused the aviation community to react and perform an assessment to determine if available certification regulations and industry standards are covering the new demands and, consequently, to work to address the identified gaps.

In line with that, the civil aviation authorities have launched a dedicated review process, in steps, of the certification specifications (also known as airworthiness standards) and accepted means of compliance of the different categories and kind of aircraft (e.g., VTOL, rotorcraft, tilt rotor, powered-lift) that is ongoing.

During the discussions held in the frame of the SAE E-40 Electrified Propulsion technical committee, the pertinence to compile and share the state-of-the-art practices for designing, integrating, and certifying an electrified propulsion system was identified. This document is the SAE response to that finding.

As the electrified propulsion is a technology in development, this document is expected to evolve to suit the new needs that may arise, to update its content to cover the evolutions of the proposed practices and to address the pending topics of the last issue.

TABLE OF CONTENTS

1.	SCOPE.....	4
1.1	Introduction	4
2.	REFERENCES.....	5
2.1	Applicable Documents	5
2.1.1	SAE Publications.....	5
2.1.2	ANAC Publications.....	6
2.1.3	ASTM Publications.....	7
2.1.4	EASA Publications	7
2.1.5	EUROCAE Publications	8
2.1.6	FAA Publications.....	8
2.1.7	IEEE Publications.....	9
2.1.8	ISO Publications.....	9
2.1.9	JCAB Publications.....	10
2.1.10	RTCA Publications	10
2.1.11	Other Publications.....	10
2.2	Abbreviations and Acronyms	10
2.3	Glossary of Terms.....	12

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2026 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, or used for text and data mining, AI training, or similar technologies, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 1-877-606-7323 (U.S. and Canada only)
Tel: 1-724-776-4970 (outside U.S. and Canada)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE AIR7128

For more information on this standard, visit
<https://www.sae.org/standards/content/AIR7128/>

Documents

Standard, visit Sharing Hub

3.	IMPACT OF PROPULSION ARCHITECTURE ON AIRCRAFT	13
3.1	Cooling	15
3.2	Energy Storage for Propulsion	16
3.2.1	Charging of Batteries	18
3.3	Electrical Power Generation and Distribution	19
3.3.1	Isolation/Discharge of Electric Energy after Aircraft Power-Off	20
3.4	Flight Performance Requirements	21
3.4.1	Flight Performance	21
3.4.2	Controllability and Maneuverability/Trim/Stability	21
3.4.3	Significance of Flight Performance Requirements for Propulsion Systems	21
3.5	Flight Controls	22
3.6	Structural Loads	22
3.7	Interdependencies for Electric and Hybrid Engine Control Systems	22
3.7.1	Coordination between Motor Controller and Combustion Engine Controller	22
3.7.2	Coordination between Motor Controllers	23
3.7.3	Motor Controller and Flight Management System Coordination	24
3.7.4	Motor Controller to Energy Storage System Coordination	24
3.7.5	Time Scaling for Controls	24
3.7.6	Communication Links	24
3.7.7	Control Link between Electric Engine Controller and Gas Turbine Engine Controller	24
3.7.8	Coordination between Thrust and Lift Functions	24
4.	ELECTROMAGNETIC ENVIRONMENTAL EFFECTS	25
4.1	HIRF Protection	25
4.2	EMI/EMC	27
4.3	Lightning Protection	28
4.3.1	Electrical and Electronic System Lightning Protection	29
4.3.2	Structural Lightning Protection	29
4.3.3	Fuel System Lightning Protection	30
4.4	Precipitation Static	30
4.5	Portable Electronic Devices (PEDs)	32
4.6	Design Considerations (Wiring, Electrical Bonding, Airframe)	33
4.7	Electrostatic Discharge (ESD)	33
4.8	Design Considerations for Electrical Wiring Interconnecting Systems (EWIS)	34
5.	SAFETY CONSIDERATIONS	34
5.1	Batteries	34
5.2	Passenger and Crew Safety (Ground and Flight)	35
5.3	Emergency Landing	37
5.4	Failure Modes for Interdependencies in Electric and Hybrid Engine Control Systems	39
5.4.1	Thrust Malfunctions	39
5.4.2	Overspeed and Overtorque Events	39
5.4.3	Loss of Electrical Supply	39
5.4.4	Load Drop/Load Accept Cases	39
5.4.5	Safety Assessment and Possible Accommodations	40
6.	VALIDATION AND VERIFICATION CONSIDERATIONS	41
6.1	Validation	41
6.2	Verification	41
6.2.1	Verification/Test Level versus Complexity	41
6.2.2	Engine and Engine Integration Verification Tests	41
6.2.3	Propulsion Battery Verification Tests	42

7.	ENGINE CERTIFICATION CONSIDERATIONS	43
7.1	Engine Certification Tests	44
7.1.1	Engine Endurance and Durability	45
7.1.2	Initial Maintenance Inspection (IMI)/Durability	47
7.1.3	Vibration	47
7.1.4	Overtorque	48
7.1.5	Calibration	48
7.1.6	Engine Overtemperature	48
7.1.7	Operation	48
7.1.8	Engine System and Component Tests	49
7.1.9	Rotor Locking	50
7.1.10	Overspeed	50
7.1.11	Rotor Burst and Rotor Unbalance	50
7.1.12	Engine/Propeller System Tests	50
8.	PROPELLER CERTIFICATION CONSIDERATIONS	51
9.	POWERPLANT CERTIFICATION AND INTEGRATION CONSIDERATIONS	51
9.1	Powerplant Fire Protection	51
9.1.1	Aircraft (Fire Risk) Zoning	54
9.1.2	Fire Detection and Protection	56
9.2	Thermal Management	58
9.2.1	Power Electronics - Thermal Management	58
9.2.2	Batteries - Thermal Management	59
9.3	Fuel	59
9.4	Lubrication	59
9.5	Cockpit Indications and Alerts	60
9.6	Controllers	63
10.	NOTES	66
10.1	Revision Indicator	66
APPENDIX A	EWIS - CFR'S CHECKLIST	67
APPENDIX B	MAPPING OF THE AVAILABLE FAA ELECTRIC ENGINE SPECIAL CONDITIONS AND THE VARIOUS SECTIONS IN AIR7128	71
APPENDIX C	COLLECTION OF REFERENCES FOR SECTION 4 TOPICS	72
Figure 1	Generalized functional architecture	14
Figure 2	Parallel hybrid propulsion architecture	23
Figure 3	Turboelectric propulsion architecture	23
Figure 4	High voltage symbol	37
Figure 5	Typical FADEC system	64
Table 1	Safety classification example	35
Table 2	Illustrative example	44

1. SCOPE

This document provides a comprehensive compilation of currently available practices, standards, regulations, and guidance material that have been considered relevant for developing an electrified propulsion system (independently or as part of an aircraft) and that may also help the applicants in the process of building their own certification approach with their Authority. It also covers unique considerations for electrified propulsion development and aircraft integration. It focuses on the particularities introduced by the new technology.

This document is not intended to represent a proposed Means of Compliance (MoC) with any particular certification regulation.

1.1 Introduction

Even with the document's scope being limited to the development specificities of electrified propulsion, a complete coverage is not possible due to the complexity of the subject matter. As multiple approaches can be followed to achieve the various objectives covered by this document, it's beneficial to provide some notes and respective rationale about how the document is organized to provide the appropriate context to those looking to leverage the information contained within.

In order to maintain homogeneity among the different sections, the following guidelines have been followed with respect to their content:

- Start with a short introduction about the topic and why it is included in the document. The description needs to take into account the architectures covered by AIR8678 and should describe the specificities of the topic in relation to the electrified propulsion, highlighting the differences to be considered with respect to combustion engines.
- Include reference to applicable certification requirements related to the topic by different authorities such as EASA or the FAA and for the different kinds of products.
- Include reference to the specific MoC (e.g., Special Condition, Advisory Circular, etc.) or CAA(s) accepted industry standards¹ (SAE, ASTM, EUROCAE, RTCA, ...) when available, complemented with examples of application when considered appropriate.

For cases where no clear references are found in the existing rules, gaps will be identified and, if possible, industry standards, industry practices, or examples of approaches that have worked for similar cases in legacy aircraft/engines or in other applications will be described to help applicants (engine suppliers or aircraft integrators) developing their own approach² with CAA(s).

One of the difficulties in determining appropriate content to include comes from the decision to cover both the possibility of developing an electrified propulsion system as part of an integrated aircraft or as an independent engine product. This has led to the need to reference engine regulations (as the EASA SC E-19 or the FAA SC for magniX™ engines) and to include specific sections associated to engine related matters.

Technical content begins in Section [3](#) with a comparative analysis outlining potential impact on the aircraft integration activities of an all-electric propulsion architecture versus a traditional combustion engine installation. That section also identifies the main topics that are affected by the introduction of the new technology, some of which are further developed in other subsections of the document, as necessary.

¹ Although in some paragraphs a particular issue is quoted, it is the applicant's responsibility to check which is the revision, amendment, or issue of the standard accepted by the relevant certification authority for each particular case, not always is the latest available one.

² This is the reason why some sections, such as Section [4](#) or [9.1](#), are quite extensive with respect to legacy approaches and why it is insisted that the use (for the certification of a given product) of proposed standards that are not part of the accepted MoCs with the applicable regulation needs to be agreed with the CAA's.

Common aircraft/engine topics are developed in Sections 4 to 6 and product particularities are highlighted as needed. Sections 7 and 8 address engine and propeller certification considerations, respectively, the main difference being that the propeller certification approach is unaffected by the introduction of electrified propulsion. Hence, it's included here mainly for the sake of completeness. The powerplant certification and integration considerations document sections come after, just in case integrated aircraft certification is sought.

The document intends to address development and certification aspects (including design and validation and verification) that should not be confused. When certification aspects are discussed, reference is made in the text to relevant certification regulation or guidelines.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

Note that, although some paragraphs quote a particular issue, it is the applicant's responsibility to check which is the revision, amendment, or issue of the standard accepted by the relevant certification authority for each particular case, not always is the latest available one.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

AIR4250	Electronic Engine Control Specifications and Standards
AIR5924	Guidelines for the Integration of Electronic Engine Control Systems for Transport Category (Part 25) and General Aviation (Part 23) Aircraft
AIR6127	Managing Higher Voltages in Aerospace Electrical Systems
AIR6258	Fiber Optic Sensors for Aerospace Applications
AIR6343	Design and Development of Rechargeable Lithium Battery Systems for Aerospace Applications
AIR6897	Battery Management Systems for Rechargeable Lithium Batteries Used in Aerospace Standards
AIR7058	High-Voltage DC Electromechanical, Solid State, and Hybrid Switching Devices in Aerospace Applications
AIR7130	Assessment of Electric Engine Failures Leading to LOPC
AIR7258	Pyrotechnic Actuator for Fast Action Electrical Protection in HVDC Aerospace Application
AIR8678	Architecture Examples for Electrified Propulsion Aircraft
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP4256	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft
ARP4754	Guidelines for Development of Civil Aircraft and Systems

ARP4761	Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment
ARP5412	Aircraft Lightning Environment and Related Test Waveforms
ARP5413	Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
ARP5414	Aircraft Lightning Zone
ARP5415	User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
ARP5416	Aircraft Lightning Test Methods
ARP5577	Aircraft Lightning Direct Effects Certification
ARP5583	Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment
ARP5672	Aircraft Precipitation Static Certification
ARP5757	Guidelines for Engine Component Tests
ARP6205	Transport Airplane Fuel System Lightning Protection
ARP7131	Verification Process for Thermal Runaway Mitigation in Large Electrical Energy Storage Powertrain Systems in Normal Category Aircraft and Rotorcraft
ARP8676	Nomenclature and Definitions for Electrified Propulsion Aircraft
ARP60493	Guide to Civil Aircraft Electromagnetic Compatibility (EMC)
AS6802	Time-Triggered Ethernet
AS8034	Minimum Performance Standard for Airborne Multipurpose Electronic Displays
AS8055	Minimum Performance Standard for Airborne Head Up Display (HUD)
SAE J1766	Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing
SAE J2344	Guidelines for Electric Vehicle Safety
SAE J2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing
SAE J2929	Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells

2.1.2 ANAC Publications

Special Class Airworthiness Criteria for the aircraft model EVE-100 from EVE Soluções de Mobilidade Aérea Urbana LTDA

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9500, www.astm.org.

ASTM F3083	Standard Specification for Emergency Conditions, Occupant Safety and Accommodations
ASTM F3230	Standard Practice for Safety Assessment of Systems and Equipment in Small Aircraft
ASTM F3239	Standard Specification for Aircraft Electric Propulsion Systems
ASTM F3235	Standard Specification for Aircraft Storage batteries
ASTM F3338	Standard Specification for Design of Electric Engines for General Aviation Aircraft

2.1.4 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

CS-23	Certification Specifications for Normal-Category Aeroplanes
CS-25	Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes
CS-27	Certification Specifications, Acceptable Means of Compliance and Guidance Material for Small Rotorcraft
CS-29	Certification Specifications, Acceptable Means of Compliance and Guidance Material for Large Rotorcraft
CS-E	Certification Specifications and Acceptable Means of Compliance for Engines
CS-P	Certification Specifications and Acceptable Means of Compliance for Propellers
SC E-19	Special Condition Electric/Hybrid Propulsion System
SC VTOL	Special Condition – Vertical Take-Off and Landing (VTOL) Aircraft
SC-LSA-F2480-01	Special condition applicable to LSA Propulsion Batteries
AMC 20-1	Certification of Aircraft Propulsion Systems Equipped with Electronic Control Systems
AMC 20-3	Certification of Engines Equipped with Electronic Engine Control Systems
AMC 20-115	Airborne Software Development Assurance Using EUROCAE ED-12 and RTCA DO-178
AMC 20-136	Aircraft Electrical and Electronic System Lightning Protection
AMC 20-158	Aircraft Electrical and Electronic System High-Intensity Radiated Fields (HIRF) Protection
AMC 25-11	Electronic Flight Deck Displays

2.1.5 EUROCAE Publications

Available from EUROCAE, The MINT Building, 2 Avenue François Mitterrand, 93210 Saint-Denis, France, Tel: +33 1 49 46 19 65, www.eurocae.net.

ED-14	Environmental Conditions and Test Procedures for Airborne Equipment, sections and appropriate test levels
ED-105	Aircraft Lightning Test Methods
ED-107	Guide to Certification of Aircraft In A High-Intensity Radiated Field (HIRF) Environment
ED-248	Guide to Civil Aircraft Electromagnetic Compatibility (EMC)
ED-289	Guidance on Determination of Accessible Energy in Battery Systems for eVTOL Applications
ED-290	Guidance on High Voltage Definition and Consideration for Personal Safety
ED-308	Guidance on VTOL Charging Infrastructure
ED-309	Guidance on VTOL Energy Level Information Provided to the Crew
ED-312	Guidance on Determining Failure Modes of Lithium-Ion Cells for EVTOL Applications
ED-321	Guidance material for endurance substantiation of electric/hybrid propulsion systems (EHPS)

2.1.6 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

Part 23	Airworthiness Standards: Normal Category Airplanes
Part 25	Airworthiness Standards: Transport Category Airplanes
Part 27	Airworthiness Standards: Normal Category Rotorcraft
Part 29	Airworthiness Standards: Transport Category Rotorcraft
Part 33	Airworthiness Standards: Aircraft Engines
Part 35	Airworthiness Standards: Propellers
FAA 2020-23434	Special Conditions: magniX™ USA, Inc., magni250 and magni500 Model Engines
FAA 2021-19926	Special Conditions: magniX™ USA, Inc., magni350 and magni650 Model Engines; Electric Engine Airworthiness Standards
FAA 2024-04690	Special Class Airworthiness Criteria for Joby Aero, Inc. Model JAS4-1 Powered-Lift
FAA-2022-1641	Special Conditions: BETA Technologies Inc. Model H500A Electric Engines
FAA-2023-0587	Special Conditions: Safran Electric & Power S.A. Model ENGINE™ US100A1 Electric Engines
FAA 2024-11192	Special Class Airworthiness Criteria for the Archer Aviation, Inc. Model M001 Powered-Lift

AC 20-88	Guidelines on the Marking of Aircraft Powerplant Instruments (Displays)
AC 20-136	Aircraft Electrical and Electronic System Lightning Protection
AC 20-158	The Certification of Aircraft Electrical and Electronic Systems for Operation in the High-intensity Radiated Fields (HIRF) Environment
AC 20-184	Guidance on Testing and Installation of Rechargeable Lithium Battery and Battery Systems on Aircraft
AC 20-190	Aircraft Electromagnetic Compatibility Certification
AC 25.856-1	Thermal/Acoustic Insulation Flame Propagation Test Method Details
AC 25-863-1	Flammable Fluid Fire Protection
AC 25.981-1	Fuel Tank Ignition Source Prevention Guidelines
AC 33-2	General Type Certification Guidelines for Turbine Engines
AC 33-5	Turbine Engine Rotor Blade Containment/Durability
AC 33.17	Engine Fire Protection
AC 33.63	Turbine Engine Vibration
AC 33.74	Turbine Engine Continued Rotation and Rotor Locking
AC 33.90	Initial Maintenance Inspection (IMI), 14 CFR 33.90, Test for Turbine Engines
AC 33.91	Engine System and Component Tests

2.1.7 IEEE Publications

Available from IEC Secretariat, 3 rue de Varembe, PO Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 0211, www.iec.ch.

IEEE Std C95.1-2019	IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz
---------------------	---

2.1.8 ISO Publications

Copies of these documents are available online at www.iso.org/store.

ISO 2685	Aircraft — Environmental test procedure for airborne equipment — Resistance to fire in designated fire zones
ISO 6469	Electrically propelled road vehicles — Safety specifications
ISO 16750	Road vehicles — Environmental conditions and testing for electrical and electronic equipment
ISO 17409	Electrically propelled road vehicles — Conductive power transfer — Safety requirements
ISO 19453	Road vehicles — Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles
ISO 21498	Electrically propelled road vehicles — Electrical specifications and tests for voltage class B systems and components

2.1.9 JCAB Publications

Circular No. 1-031 Policy of special conditions application for electric vertical take-off and landing aircraft³

2.1.10 RTCA Publications

Available from RTCA, Inc., 1150 18th Street NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment, sections and appropriate test levels

RTCA DO-311 Minimum Operational Performance Standards for Rechargeable Lithium Batteries and Battery Systems

2.1.11 Other Publications

DEF STAN 00-970 Design and Airworthiness Requirements for Service Aircraft

JSSG-2007 Joint Service Specification Guide – Engines, Aircraft, Turbine

JSSG-2009 Joint Service Specification Guide – Air Vehicle Subsystems

MIL-HDBK-516 Airworthiness Certification Criteria

MIL-STD-1553 Aircraft Internal Time Division Command/Response Multiplex Data Bus

NAVSEA Technical Manual OP 3565/NAVAIR 16-1-529 VOLUME 1, "Electromagnetic radiation hazards to personnel, fuel and other flammable materials (2003)"

2.2 Abbreviations and Acronyms

A/C	aircraft
AAM	advanced air mobility
AC	Alternating Current/Advisory Circular
AFDX	Avionics Full-Duplex Switched Ethernet
AIR	aerospace information report
AMC	Accepted Means of Compliance
ANAC	Agência Nacional de Aviação Civil
ASMET	accelerated simulated mission endurance test
ASTM	American Society for Testing and Materials
BITE	built-in test equipment
BMS	battery management system

³ This circular from JCAB provides guidelines regarding additional conditions to be considered in Airworthiness Inspection Manual, Part II in order to demonstrate compliance of eVTOL with the standards in Annex 1 of the Regulation for Enforcement of the Civil Aeronautics Act. <https://www.mlit.go.jp/koku/content/001855393.pdf>

CAA(s)	Certification Authority(ies)
CAN	controller area network
CFR	Code of Federal Regulations
CMT	Certification Management Team (ANAC-EASA-FAA-TCCA)
DC	direct current
DFZ	designated fire zones
EASA	European Union Aviation Safety Agency
EHPS	electric/hybrid propulsion system
EME	electromagnetic effects
EMI	electro-magnetic interference
EOS	electrical overstress
EPU	electric propulsion unit
ESD	electrostatic discharge
ESS	energy storage system
EUROCAE	European Organisation for Civil Aviation Equipment
EWIS	electrical wiring interconnecting systems
FAA	Federal Aviation Administration
FADEC	full authority digital engine control
FET	field-effect transistor
FPGA	field programmable gate array
HBM	human body model
HCF	high cycle fatigue
HIRF	high-intensity radiated fields
HV	high voltage
HW	hardware
IGBT	insulated-gate bipolar transistor
ISA	International Standard Atmosphere
ISO	International Organization for Standardization
JCAB	Japan Civil Aviation Bureau

LCF	low cycle fatigue
LOPC	loss of power control
LRU	line replaceable unit
LSA	light sport aircraft
LV	low voltage
MM	machine model
MoC	Means of Compliance
NAWCAD	Naval Air Warfare Center Aircraft Division
PEDs	portable electronic devices
RF	radio frequency
RTCA	Radio Technical Commission for Aeronautics
SC	Special Condition
SoC	state of charge
SoH	state of health
SW	software
TCCA	Transport Canada Civil Aviation
TSO	Technical Standard Order
TST	Task Specific Team as set up by CMT
VTOL	vertical takeoff and landing
WIP	work in progress
WLAN	wireless local area network

2.3 Glossary of Terms

For a detailed glossary of terms used in this document and all E-40 Committee works, please refer to ARP8676.

3. IMPACT OF PROPULSION ARCHITECTURE ON AIRCRAFT

The selected propulsion architecture impacts other systems and ultimately the aircraft design. An example of a generalized electrified propulsion architecture (extracted from AIR8678) can be found in [Figure 1](#). Its complexity in terms of variety of fluids (air, fuel, hydrogen, coolant, hydraulic...) and energy (thermal, mechanical, electrical...) to be handled by the propulsion subsystems, has a big influence on the integration efforts in all aspects.

In this regard, the introduction of electrical engines simplifies the installation with respect to combustion engines in some of the following aspects:⁴

- No need to ensure safe disposal of combustion exhaust gases, that may cause a fire, contaminate personnel compartments, affect aircraft structure, or affect control surfaces. Consequently, exhaust nozzles are not required.
- No need to include provisions for fuel drains.⁵ The safe disposal of drained fuel in case of pipe rupture in the nacelle areas is a complicated task that affects the nacelle design; hence getting rid of it is a clear advantage.
- No need to implement flammable fluid mitigation means devoted to fuel (although they may be needed for other reasons, such as lubrication or cooling).
- Due to the significantly higher efficiency of the electric engines with respect to combustion engines,⁶ engine heat rejection is considerably reduced, and hence engine and (potentially) nacelle cooling needs, particularly on high ISA days in some areas of the envelope as ground operation, low speed combined with high power conditions in flight or during soak back. Accordingly, high temperature requirements for the systems located nearby the electrical motor may be more relaxed.
- For the same power, engine size is reduced. Engine response to power requests from control may increase considerably (e.g., time to achieve the desired power is reduced).
- No need to cater for continuous supply in all operating conditions of substantial amount of air with the stringent requirements of cleanliness (e.g., particles), pressure uniformity at engine intake, flow direction, turbulence, and speed.
- Electric engines are less susceptible to external temperature and pressure variations and may be exposed, due to their possibility of being located inside the aircraft, to more benign climatic conditions (rain, snow, freezing fog, ice accretion...).
- The reduction in engine noise level and emissions simplify the compliance with these aspects at A/C level.
- Engine complexity is reduced and also installation requirements (no starter motor, no ducts for handling bleed valves, no fuel piping, valves and pumps, etc.). Engine reliability can be positively affected.
- Engine manufacture is simpler and consequently cheaper.
- Engine maintenance requirements are lower and maintenance techniques simpler. This implies lower engine accessibility requirements (e.g., boroscopic ports, accessibility constraints, etc.). Fewer human interventions go in parallel with reduction of maintenance mistakes or accidental damage.

The elimination of the above-mentioned constraints gives the designers more freedom to explore disruptive concepts. It facilitates, for instance, the possibility to increase the number of engines installed, to have more flexibility in terms of location (e.g., the tip of the wings) and to use them for different purposes than just for propulsion.

⁴ Combustion engine versus electrical motor comparison only.

⁵ Note that drainage requirements do not only apply to fuel but also to other liquids as hydraulic, lubricating, or cooling fluids or condensation water for different reasons (e.g., fire prevention, ice formation avoidance...). Fuel is quoted here because, in combustion engines, its quantity with respect to the rest is, by far, the highest.

⁶ Note that the comparison done is simplistic because is centered at engine level only. When considering the complete propulsion system, depending on the architecture (see [Figure 1](#)), other losses need to be taken into account to get a true picture of the global efficiency. See [3.1](#) and [9.2](#) for a deeper assessment of cooling and thermal management topics.

For example, the distributed propulsion concept consists of introducing an array of propulsors on the aircraft. It applies to fixed wing and rotary-wing aircraft. This can be used:

- In fixed-wing aircraft, to blow air into the wing extrados to increase the lift.
- In fixed-wing aircraft, for wing boundary layer ingestion to reduce parasitic drag.
- For directional control, by applying differential thrust: with this the need to control surfaces (e.g., ailerons, flaps, rudders) on fixed-wing aircraft or torque compensating means (contra-rotating rotors or tail rotors) on rotorcrafts may be reduced or eliminated.

This is quite attractive but has also drawbacks; in the case of the last bulleted item, relying only on the propulsion system to perform these control tasks increases the exposure of the aircraft to propulsion related failure conditions that need to be compensated somehow and may be a source of common cause failures that need to be captured by a thorough safety analysis.

As electric engines have much higher dynamics in terms of power availability compared to classical turbine engines, another side effect to be studied is the impact on the aircraft of the transient conditions generated after events such as thrust malfunctions, overspeed, or overtorque. The corresponding failure accommodations need to cater for the quickest potential failure effects. This is further discussed in [3.7](#) and [9.6](#).

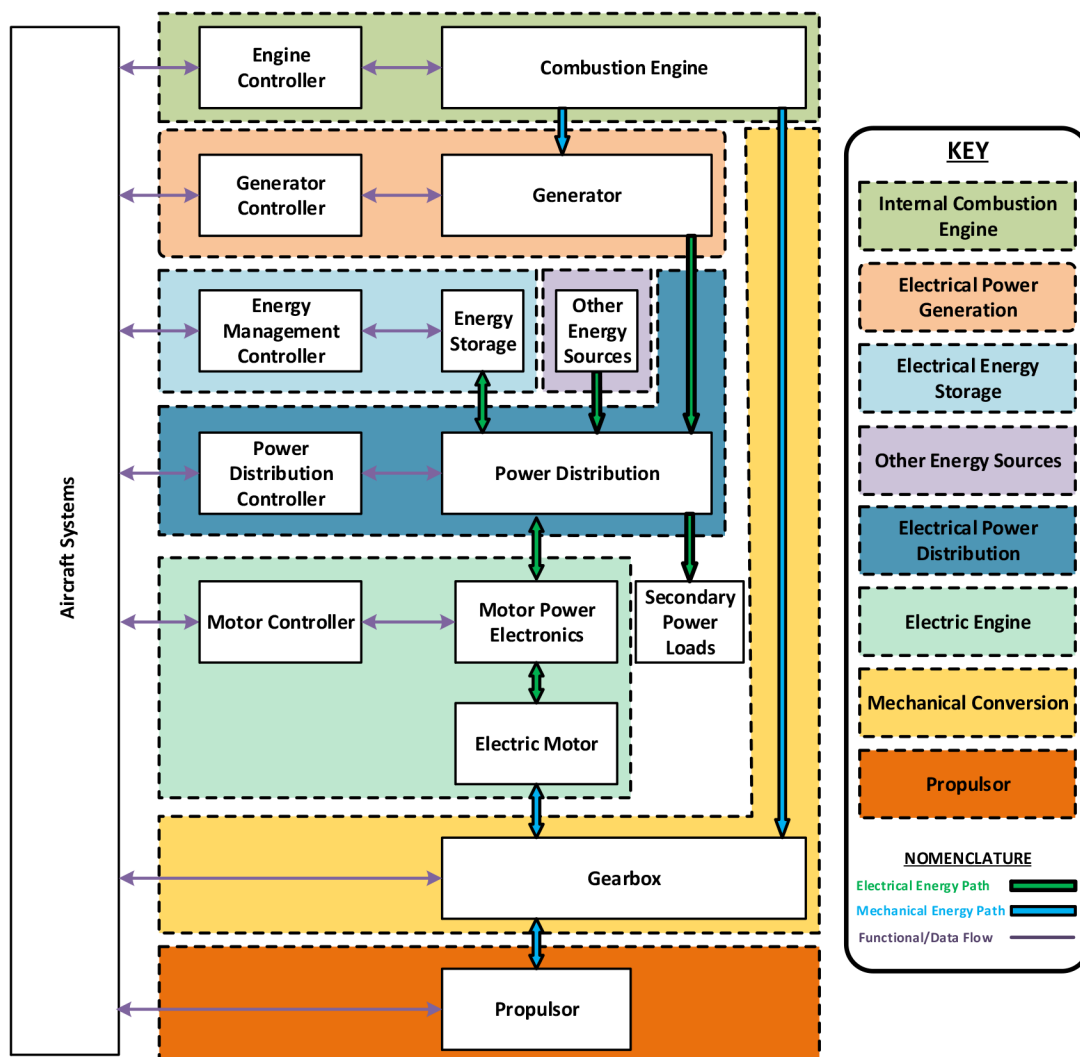


Figure 1 - Generalized functional architecture
 Reprinted with permission from AIR8678. © SAE International

3.1 Cooling

The different elements of the electrified propulsion architectures have their own cooling needs. One important aspect of the integration activities is to ensure that the temperature of their components (including fluids) is maintained within the required limits in all the expected working conditions to prevent a reduction in aircraft capability, malfunctions, and adverse impacts on their service life. The certification regulations include requirements related to this need at both the engine level (refer to paragraphs as EASA CS-E 80, 260, 440, 660, 740 or FAA 14 CFR 33.21, 33.49, 33.87 for combustion engines or EASA EHPS.320 and FAA special condition no. 6 for magniX™ engines in the case of electric engines) and aircraft level (refer to, for example, EASA CS/FAA 14 CFR 25/27/29 1041 to 1045 for large airplanes/small helicopters/large helicopters).⁷

In some cases, engine cooling and lubrication (see [9.4](#)) functionalities are performed by an integrated oil system. For the engines driving a variable pitch propeller, the engine oil circuit may be linked to the propeller hydraulic system.

In the following paragraphs of this section, the heat sources of the relevant elements of the electrified propulsion architectures are described in more detail.

Electric propulsion systems do not convert energy perfectly. Some loss is generated as heat.

In the electric motor, this loss comes from several sources, that include:

- Winding conduction loss: Resistive heating of conductors in the winding because they are passing current. Sometimes referred to as “DC loss,” despite the current waveforms in the conductors not being DC.
- Winding AC loss: Eddy current loss induced in the windings as a result of proximity to the changing magnetic field of the motor.
- Iron loss: Eddy current loss induced in the iron of the motor due to changing magnetic fields. Many motors use a laminated core where thin (e.g., 0.35 mm thick) sheets of electrical steel are stacked to form the iron components. These sheets have an electrically insulated coating on both sides to prevent conduction (and hence minimize eddy current loss). Iron loss occurs in the stator and rotor iron where such parts are included.
- Stray load loss: Other losses that occur in electrical machines when load current flows, due to stray currents and leakage magnetic flux. They are caused by eddy currents induced in structural parts, case, or other conductive components by the leakage flux generated during operation under load.
- Magnet loss (where magnets are used): Eddy current loss due to changing magnetic fields in the magnets.
- Windage: Loss generated from moving air internal to the machine due to rotation.
- Friction (mechanical): Drag loss from rotor support bearing system or integral gear boxes.

The proportion of the losses are subject to operating conditions, increasing with both speed and load. Winding loss (conduction and AC) and iron losses tend to dominate at any appreciable speed or load.

Remanence of the magnet is inversely proportional to temperature. In other words, a hotter magnet produces less field strength and ultimately reduces motor output torque for a given input current.

Although magnet loss magnitude is often small compared to other loss mechanisms, the high thermal resistance between magnets and heat rejection provision can make maintaining magnet temperature challenging.

The conduction losses in the motor depend on its winding resistance and both increase as winding temperature rises.

⁷ The list of paragraphs is not exhaustive.

Magnet failure (significant loss of output) can be because of overheating such that the curie temperature for the magnet grade in question is exceeded and may be an irreversible condition. A higher temperature magnet is also less resistant to demagnetization, becoming damaged at a lower opposing field strength than a cooler magnet of the same type. Maintaining robustness against large opposing field strength from a sudden short circuit is key to achieving a suitable life of the motor, so magnets running hot will require higher material properties to be robust enough to demagnetization from sudden short circuit.

On propulsion batteries, heat is generated in the cells by two main sources:

- Joule effect due to internal cells resistance
- Entropy changes during the electrochemical reactions

In a simplified model, in working conditions (no thermal runaway), heat depends on the intensity of the current, the open circuit voltage, the cell's nominal voltage, and the temperature.

Within the power electronics (inverter), losses are also incurred. These are generally categorized as:

- Power module conduction losses. These are caused by the imperfect “on” state of the semiconductor switching elements in the power module. Losses are incurred as a result of the current flowing while incurring a voltage drop.
- Power module switching losses. As the switching elements take a finite time to transition from the “on” state to the “off” state and vice versa, there is a short time period during which they are conducting a high current and also sustaining a high voltage, resulting in a very high peak power loss. Although this occurs during only a very small fraction of the total switching period, the contribution to the overall conversion losses can be quite significant.
- Other high current conduction losses. These include the resistive losses due to the high currents flowing in the interconnections, both within the power module (the wire bonds and the internal electrical substrate) and also in the busbars and other high current connections within the inverter and may have a dependency on component power rating.
- Housekeeping circuit power consumption. This comprises the power required to operate the microcontroller, switch control circuits, communications, and monitoring circuits, etc. Ultimately, this power ends up as heat within the inverter housing and must be managed carefully.

For specific heat management considerations of power electronics, see [9.2.1](#), and for batteries, see [9.2.2](#).

3.2 Energy Storage for Propulsion

In combustion engines, propulsion energy is obtained through the combustion of the fuel stored in the aircraft fuel tanks. Fuels used in aviation are produced according to specifications developed by standardization groups. The list of fuels approved to be used in a particular engine is provided as part of the engine manuals.

For EHPS, electrical energy is used by the electrical motors to generate mechanical power. Electrical energy may be stored (e.g., in a battery), generated by electrochemical reactions (such as a fuel cell), or generated by an electrical generator. This issue of the document only considers batteries as a means to store and retrieve electrical energy dedicated to propulsion.

The use of batteries for propulsion has a considerable impact on aircraft integration and certification activities. Aspects such as size, weight, thermal management, energy generation and management to cope with electric engine demands, associated high voltage/intensities, chemistry, and failure modes and effects need to be addressed.

For propulsion batteries, EASA SC E-19 includes the requirement EHPS.380, dealing with the design and constructions considerations for integrating them on an aircraft,⁸ including the provisions in case that the EHPS is intended to operate in reverse mode and to recuperate energy in flight or on ground. The related MoC asks to cover the energy losses with regard to the State of Charge (SoC) and State of Health (SoH) of batteries which could help determining the maximum available power used for aircraft performance calculations.

⁸ A/Cs within the declared scope of the SC-E19. For CS-23 Normal-Category Aeroplanes up to Level 1, refer to the SC E-18.

It is important to highlight that, at the time of issuing this document, the FAA does not contemplate the certification of the propulsion battery system as part of the engine. Energy storage requirements are found at aircraft level only (refer to criterion JS2430 “Energy systems” in the Special Class Airworthiness Criteria for the Joby Aero, Inc. Model JAS4–1 Powered-Lift).

VTOL.2430 and VTOL.2445 (part of the EASA SC-VTOL specifically issued for VTOL aircraft) include requirements applicable to the energy storage system for electrified aircraft types; in particular, independence between multiple storage systems, adequate margins for safe functioning, or the need to provide relevant information of its status to the crew. In the EASA MoC for SC-VTOL, ED-289 is accepted as a means to determine the adequate margins of an electrical energy storage system required by VTOL.2430(a)(3) and to define the reliability of the relevant information to be provided to the flight crew as required by VTOL.2430(a)(4) and established in VTOL.2445(g). On the FAA side, the criterion JS4.2430 of the Special Class Airworthiness Criteria for the Joby Aero, devoted to energy systems, addresses aspects as independency, effect of lightning strikes, information to the flightcrew, isolation, crash-landing, and recharging. The JCAB have issued specific requirements for power storage systems in JCAB Circular 1-031 (§eVTOL 23.2430) to supersede the fuel system requirements in the Airworthiness Inspection Manual Part II.

For propulsion lithium batteries intended for light sport aircraft, EASA SC-LSA-F2480-01 establishes appropriate airworthiness standards. The requirements cover aspects as ensuring an adequate flow of energy for the proper engine functioning under any normal operating conditions (including any maneuver for which certification is requested and during which the EPU is permitted to be in operation), providing protection against overcharge and critical discharge of the batteries (including deep or unbalanced discharge if necessary for the type of battery), or considering the effects on the propulsion battery of the propulsion system in a windmilling condition, when the engine might work as a generator.

As recognized in the white paper on thermal runaway issued by the Certification Management Team (CMT, which includes representation from ANAC-EASA-FAA-TCCA),⁹ no TSO is available yet to cover the Propulsion Battery Systems.

ASTM F3235 covers electrical storage battery aspects of airworthiness and design and has been created by focusing on Normal Category airplanes. It includes an appendix correlating EASA CS-23 requirements with related sections of the specification.

RTCA DO-311¹⁰ provides design, testing, and installation guidance for rechargeable lithium battery systems that are permanently installed on aircraft.

AIR6343¹¹ provides a basic overview of methodologies that should be utilized when undertaking the design and development of rechargeable lithium battery systems for aerospace applications.

For safety considerations related to propulsion batteries, see Section [5](#); for propulsion battery verification tests, see [6.2.3](#); for fire precautions, see [9.1](#); and for thermal management, see [9.2](#).

⁹ Refer to the document (dated 30th of May 2024) in the link [CMTS TST \(Certification Management Team Secretariat Task Specific Team\) | EASA \(europa.eu\)](#) that includes a note of caution regarding the use of TSO C1279b for propulsion batteries.

¹⁰ The adequacy of the proposed standard to cover a particular A/C application needs to be discussed with the relevant certification Authority.

¹¹ The adequacy of the proposed standard to cover a particular A/C application needs to be discussed with the relevant certification Authority.

3.2.1 Charging of Batteries

Rechargeable batteries used for propulsion shall sustain numerous charge-discharge cycles along their service life. Implementing an appropriate management on the conditions under which these cycles take place is crucial to ensure a safe, reliable, and satisfactory aircraft operation. The charging process needs to be closely monitored; if the charging temperature is too low, the diffusion of the Li ions is slowed down and induces the growth of dendrites in the anode that may cause internal short circuits. If charging is done beyond the recommended maximum current, Li ions will accumulate in the anode surface¹² and cells temperature will grow up and lead to an increase of the rate of electrochemical reaction that, if not counteracted, may end in a thermal runaway.

EASA SC E-19 specific requirement for propulsion batteries is EHPS.380, but compliance guidelines regarding charging functionality have not been developed at the time of releasing this document. For Light Sport aircraft, EASA SC-LSA-F2480-01 requires providing a protection against overcharge of the batteries that includes deep or unbalanced discharge (if necessary for the type of battery). Also, that Li battery installations must have a system to control the charging rate of the battery automatically so as to prevent battery overheating or overcharging.

For VTOLs, EASA VTOL.2430 requires that each energy-storage-refilling or recharging system must be designed to prevent improper refilling or recharging, prevent contamination of the stored energy during likely operating conditions and prevent the occurrence of any hazard to the aircraft or to people during refilling or recharging. The criterium JS4.2430 of the Special Class Airworthiness Criteria for the Joby Aero also request that the recharging system must be designed to Prevent improper recharging; and the occurrence of hazard to the aircraft or to persons during recharging. JCAB for VTOLs have specific requirements for power storage systems in JCAB Circular 1-031 (§eVTOL 23.2430) that supersede the fuel system requirements in the Airworthiness Inspection Manual Part II.

As explained in AIR6897, for rechargeable Lithium Batteries used in Aerospace, a battery management system (BMS) should be incorporated to monitor the state of the cells and protect them from harmful conditions such as overvoltage, undervoltage, overcurrent, and overtemperature that can negatively impact their performance, life, and safety characteristics in all the expected operating range. With respect to the recharge cycle, the BMS typically includes the following functionalities:

- The Overvoltage Charge Protection prevents individual cells exceeding the maximum allowable voltage during charging.
- The Overtemperature Charge Protection restricts cells from charging when the cell temperature exceeds the maximum allowable charge temperature.
- The Undertemperature Charge Protection restricts cells from charging when the cell temperature is below the minimum allowable charge temperature.
- The Overcurrent Charge Protection prevents cells from exceeding the maximum allowable charge current.
- The Charge Termination, activated when some or all of the cells in the battery are brought to a full state of charge.

EUROCAE ED-308 contains minimum requirements for VTOL Charging Infrastructure and has been developed having in mind the EASA SC-VTOL (in particular the requirements VTOL.2430 c and d). This technical standard applies to electric vehicle supply equipment designated to conductively charge high voltage electrical energy for VTOL aircraft on vertiports. It is not aimed to address the performance of any VTOL equipment; it relies on ISO 17409:2020 (originally developed for road vehicles) to define the corresponding charging requirements. ISO 17409:2020 applies to the onboard section of vehicle power supply circuits and also to power supply control functions used for the connection of the vehicle to an external electric circuit.

¹² Lithium plating phenomenon that degrades the capacity of the cell, increases its internal resistance, and leads to longer charging times and accelerate aging.

3.3 Electrical Power Generation and Distribution

One of the challenges of the implementation on electrified propulsion aircraft architectures is to provide the required power within the weight constraints. Components need to contribute to achieve the performance and efficiency goals needed to have a viable and competitive design.

To get high propulsive power with EPU's, one of the key aspects is to find the right balance between voltage level and current intensity. The intensity values are limited (among other factors) by the thermal constraints inherent to the technology of the conductors (e.g., wiring impedance). The electrical systems may incorporate protections that are triggered when the temperatures of certain components (as the converters or the rectifier units) reach values beyond defined thresholds.

With traditional copper or aluminum-based conductors, the management of the heat released at high currents is a serious issue when there is the need to keep the weight of the wiring under control. An alternative, under development, is to incorporate superconductors, but it is currently linked to work at cryogenic conditions which are very complicated to handle with the available technology.

To overcome that, the easiest choice is to increase the voltage. The use of high voltages (HV) has also drawbacks, as the need to impose more stringent insulation and segregation requirements (as stated in Section 4 and 9.1), the need to handle increased short circuit currents or the need to address more severe electrical ageing. Depending on the selected architecture (see Figure 1), the high voltage (HV) can be provided by electrical generators and/or by batteries or fuel cells. Fuel cells are not covered by this issue of the document; for propulsion batteries, see 3.2.

The electrified propulsion architectures may incorporate AC and DC and, in both cases, HV and LV. HV is needed, at least, for feeding the EPU's. Normally, the HV DC must be converted to HV AC by the DC/AC inverters to feed the electrical motors.

Modern aircraft incorporate multi-voltage distribution systems with fixed and variable frequency supplies. This provides more flexibility and permits improving the overall efficiency.

The HV generated by the battery's cells is non-regulated DC; normally it must be transformed to regulated DC through DC/DC converters to power the loads. There is the need to ensure an adequate DC power quality by following appropriate design and verification directives. On road vehicles, there are available standards such as ISO 21498-2.¹³

Design precautions need to be taken to ensure an effective separation between HV and LV circuits (normally used to power avionics) to prevent dangerous consequences. Protections may consist in a mix of installation precautions (as wiring isolation and segregation) to prevent cross-contamination and use of galvanic isolation (by means of transformers, optocouplers...) or other means (as voltage limiters, diodes, fuses, contactors, insulation...) to prevent HV direct propagation. The number and type of barriers to be implemented need to address the risk and the criticality impact of the barrier failure.

Adequate protections are also needed against short-circuits leading to parallel or serial arcs. The high levels of current and voltage present during the faults also create significant magnetic forces on the cables and neighboring elements. For a deeper insight on Electromagnetic Effects, see Section 4.

The fast, dynamic nature of the above quoted faults, and the high values of the transient voltages/currents that can be reached almost instantaneously, heavily influences the selection of the protection devices. AIR7058 defines electrical switching characteristics to consider for proper selection of switching devices on aircraft applications implementing HVDC as primary source of electric power.

Protection must be extended to cover human safety, not only in flight but also during manufacturing and maintenance operations.

Other important aspects to be covered are the need to cater for stringent environmental conditions (low pressure, harsh temperatures, humidity, vibrations, higher radiation levels in altitude...) and high operational safety and reliability requirements.

¹³ Suitability of following this standard in the frame of electrified propulsion certification needs to be checked with the CAA(s).

There are papers that discuss the previously mentioned aspects thoroughly¹⁴ that can be consulted. It is not under the scope of this document to get into this kind of design details.

For large/transport category airplanes, most of the certification requirements related to electrical power generation and distribution are found in CS/FAA 14 CFR 25 subpart F (mainly paragraphs 25.1351 to 1365) and subpart H for EWIS. For normal category aircraft, they are found in EASA CS/FAA 14 CFR 23 subpart F (among them 23.2525), for small rotorcrafts in EASA CS/FAA 14 CFR 27.1351 to 1367, and for large rotorcrafts in EASA CS/FAA 14 CFR 29.1351 to 1363. For VTOL, on the EASA side, in SC-VTOL subpart F (among them VTOL.2525).

On the EASA side, SC E-19 requirement EHPS.370 applies to electrical power generation, distribution and wirings of the EHPS. FAA SCs for Beta and SAFRAN engines address in the proposed special condition no. 33 the applicable requirements to the engine electrical systems, including the distribution, the protection systems, and the required electrical power characteristics.

The JCAB have issued specific requirements for power storage systems in JCAB Circular 1-031 (§eVTOL 23.2430) to supersede the fuel system requirements in the Airworthiness Inspection Manual Part II.

The standardization bodies (as SAE AE-10, SAE AE-7) are working in developing standards to cover the generation and control, storage, conversion, distribution, load management, and utilization of electric power for aerospace vehicles. It is advisable to check the latest released documentation.

3.3.1 Isolation/Discharge of Electric Energy after Aircraft Power-Off

IEC Technical Standard 60479-1 provides a summary of the effects of electric current on the human body and on livestock.

Adequate procedures and design means shall be developed to protect maintenance workers, crew and passengers from electrical risks after aircraft power-off.¹⁵ Whenever deenergizing the electrical power circuits (that may be particularly relevant for designs that include ultracapacitors) is not practical or feasible (e.g., batteries circuit), other electrical protection barriers as isolation may be applied.

In some aircraft designs, after aircraft power-off, not all the aircraft systems may be de-powered at the same time; some systems may be temporarily active for various reasons, for example, to run a BITE for collecting and recording maintenance information post-flight. It is also possible that, for maintenance reasons, some dedicated systems may be required to be electrically activated in order to perform the required tasks. EUROCAE ED-290 contains guidance for definition of high voltage (HV) and electrical hazards on VTOL and consideration on personal safety. It has been developed to support the showing of compliance with some requirements of the EASA SC VTOL and includes a lock-out procedure for ground operation that enables authorized people to safely have access to HV electrical installation/equipment parts for maintenance purpose. This procedure requires a switch-off of the electrical power lines upstream the electrical installation/equipment, a discharge of the HV network (including any equipment internal capacitor), a physical separation in open-circuit of the electrical installation/equipment from its source of power/energy, a lockout-tagout to make sure that the system cannot be switched-on, a confirmation of the voltage absence via a Voltage Absence Tester, a grounding of all HV phases under defined conditions, and an insulation form that has to be filled-in in some explained circumstances.

¹⁴ Refer to H. Schefer, L. Fauth, T. H. Kopp, R. Mallwitz, J. Friebe, and M. Kurrat, "Discussion on Electric Power Supply Systems for All Electric Aircraft," in *IEEE Access*, vol. 8, pp. 84188-84216, 2020, doi: 10.1109/ACCESS.2020.2991804. Also: I. Echavarria, M. Silvestre, M. Nüsseler, "Challenges Associated to High Power Hybrid Electric Propulsion in Aerospace," NATO STO MP-AVT-323-04.

¹⁵ For the particular case of the emergency landing, see [6.2](#).

3.4 Flight Performance Requirements

The flight performance group of requirements fall under the Subpart B – Flight section of the EASA/FAA airworthiness regulations. They include requirements related to aircraft performance and flight characteristics (controllability, trim, stability)

3.4.1 Flight Performance

For large/transport category airplanes, performance certification requirements are found in EASA CS/FAA 14 CFR from 25.101 to CS 25.119. They are aimed to demonstrate that the aircraft has adequate flight performance in different flight phases (takeoff, climb, landing) and engine failure scenarios. For normal category aircraft, performance requirements are found in EASA CS/FAA 14 CFR 23.2115 to 23.2130, for small rotorcrafts in EASA CS/FAA 27.49 to 27.87, and for large rotorcrafts in EASA CS/FAA 29.49 to 29.87. For VTOL the performance requirements are described in EASA VTOL2115 to VTOL 2130 and comparable sections of FAA VTOL airworthiness criteria.

3.4.2 Controllability and Maneuverability/Trim/Stability

For large/transport category airplanes, controllability and maneuverability certification requirements are found in EASA CS/FAA 14 CFR from 25.143 to CS 25.149. They are aimed to demonstrate that adequate means are incorporated in the design to ensure that the aircraft is safely controllable and maneuverable during operation in all flight phases, including one or second engine failures (for aircraft with three or more engines), when control surfaces (high lift devices, ailerons, rudder, deceleration devices...) are activated, in maneuvers such as go-around, and under defined icing conditions. For normal category aircraft, controllability requirements are found in EASA CS/FAA 14 CFR 23.2135, for small rotorcrafts in EASA CS/FAA 14 CFR 27.143, and for large rotorcrafts in EASA CS/FAA 14 CFR 29.143. For VTOL, the controllability requirement corresponds, on the EASA side, to VTOL2135.

The introduction of the electrified propulsion, per se, does not necessarily imply a change in the demonstration activities for the above-mentioned paragraphs, only the already commented impact (see Section 3) of the expected quicker reaction times (on nominal and failure conditions) of the electric engines need to be addressed. However, in case that differential thrust or thrust vectoring were used in normal category or large aircraft for directional control, there may be an impact to be discussed with the certification Authorities, but this is not specific to electrified propulsion implementation.

Similarly occurs for the trim (EASA CS/FAA 14 CFR 25/27/29.161 or 23.2135 or VTOL.2140 as applicable) and stability certification requirements (EASA CS/FAA 14 CFR 25/29.171 to 181 or 27.171 to 177 or 23.2145 or VTOL.2145 as applicable).

3.4.3 Significance of Flight Performance Requirements for Propulsion Systems

Aircraft performance requirements have a large influence on the engine and propulsion system design in terms of power/thrust ratings in normal operation, power/thrust requirements, and failure rate targets for partial and total loss of engine power output. Aircraft takeoff performance characteristics depend on the engine takeoff power/thrust ratings. Aircraft Climb performance requirements help determine the maximum continuous power/thrust requirements for the engine including capacity sizing and its cooling system. Aircraft performance in case of a partial failure in an electric engine depends on the power remaining, which is driven by the electrical redundancy (dual, triple, quad inverter system) and engine sizing margin. In electric engines, significant partial power loss (25 to 50%) can occur with single electrical/electronic failures (due to high voltage power electronics) at a higher probability than in traditional combustion engines which had minor (10 to 15%) power loss for such single failures. So it becomes important to evaluate aircraft performance and safety risk for these likely partial power loss failure modes with electric engines in general and for single engine aircraft in particular. Similarly, on multi-engine aircraft, partial or total power loss on one engine leads to asymmetric thrust which is a controllability challenge for the aircraft.

3.5 Flight Controls

For large/transport category aircraft, most of the certification requirements related to flight controls are found in the subpart C (in particular, the “Control Surface and System Loads” part), subpart D (mainly “Control Surfaces” and “Control Systems” parts), and subpart F of EASA CS/FAA 14 CFR 25. Current version of this regulation and the associated guidance material is oriented to traditional aircraft configurations; hence, in case of aircraft architectures implementing differential thrust or thrust vectoring on the propulsion system, flight control system requirements need to be applied in addition to propulsion system requirements in the compliance demonstration. The flight control system includes, at a minimum, the equipment and systems used for control of pitch, roll, yaw, and vertical motion and all supporting systems and equipment. The subsystem analysis for the engine power or thrust control system needs to be supplemented with compliance to flight controls requirements and system safety requirements.

For normal category aircraft, latest issue of the EASA/FAA regulations are performance based (non-prescriptive); therefore, they are not so specific to a particular aircraft design. Certification requirements related to flight controls are mainly found in subpart C, subpart D, and subpart F of EASA CS/FAA 14 CFR 23.

For VTOL aircraft, on the EASA side, refer to the equivalent sections of SC for VTOL that is also performance based. JCAB includes flight control system requirements in the Airworthiness Inspection Manual Part II, plus the specific requirements of JCAB Circular 1-031 (refer to §eVTOL 23.2300).

For small rotorcrafts, refer to EASA CS/FAA 14 CFR 27, and for large rotorcrafts, refer to EASA CS/FAA 14 CFR 29.

As for the previous subsection, it is considered that the introduction of the electrified propulsion does not necessarily imply a change in the demonstration activities for the above-mentioned regulations.

3.6 Structural Loads

In case of large aircraft powered with all electric engines, the demonstration strategy for current version of EASA CS/FAA 14 CFR 25.367 dealing with asymmetrical loads due to engine failure need to be discussed with the certification Authorities to find appropriate replacement to the failure cases related to the fuel flow interruption, disconnection of the engine compressor from the turbine or from loss of the turbine blades. Also, for determining engine failure conditions to derive the corresponding loads for EASA CS/FAA 14 CFR 25.362 compliance.

When differential thrust or thrust vectoring is used in normal category or large aircraft for directional control, instead of, or in combination with, more traditional control surfaces, care must be taken to ensure that load cases contemplate the corresponding loads and momentums and the exposed powerplant elements contribute to the certification compliance demonstration, but, again, this is not specific to electrified propulsion implementation.

3.7 Interdependencies for Electric and Hybrid Engine Control Systems

The key elements of a hybrid electric propulsion system are shown in [Figure 1](#). The interdependencies between electric motor controllers, gas turbine engine controllers, aircraft flight management, and energy storage and distribution systems depend on the system architecture; hence the analysis done in this section is limited in nature. AIR8678 outlines six architectures (viz., All Electric, Parallel Hybrid, Series Hybrid, Turboelectric, Partial Turboelectric, and Combined Series-Parallel). Parallel Hybrid and Turboelectric architectures will be used here to discuss the interdependencies.

3.7.1 Coordination between Motor Controller and Combustion Engine Controller

In the case of the parallel hybrid architecture (see [Figure 2](#)), the aircraft propulsion system is composed of a gas turbine engine and an electric engine providing power to the propeller through a gearbox. This requires close coordination between the motor controller and the combustion engine controller to manage mechanical power to generate thrust or lift in a stable and responsive manner in normal operation and in faulty conditions, to support aircraft controllability.

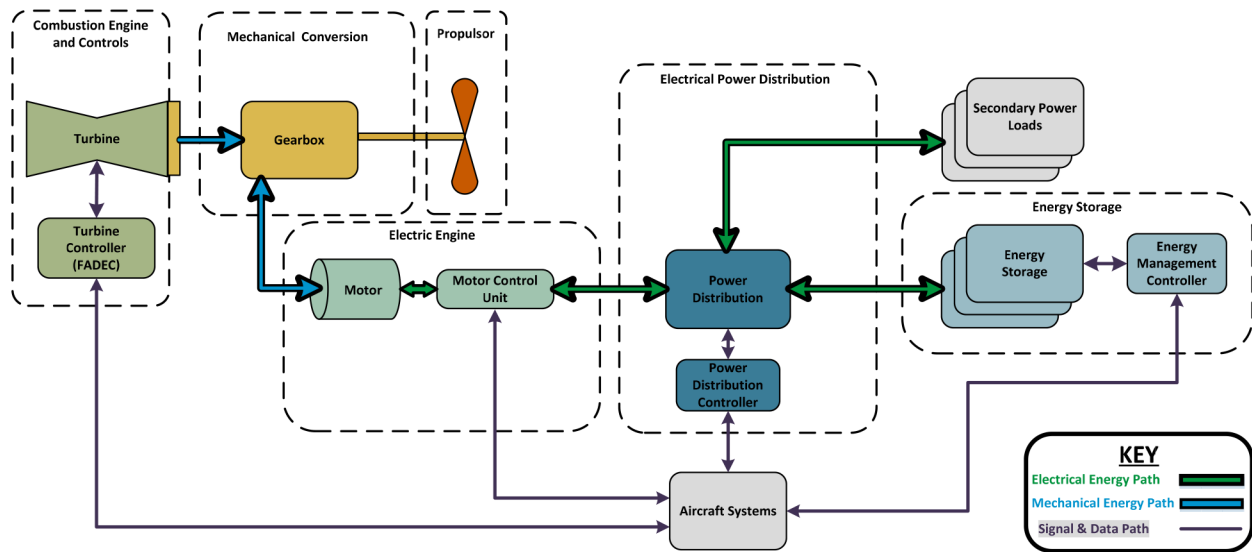


Figure 2 - Parallel hybrid propulsion architecture
 Reprinted with permission from AIR8678. © SAE International.

3.7.2 Coordination between Motor Controllers

In a distributed, turboelectric architecture (see [Figure 3](#)), the propulsive power (either thrust or lift) is produced only by electric engine(s). In this case, some functional links are required between motor controllers, addressing the interdependencies as described in this section (power balancing, synchro phasing, etc.). Note that in [Figure 3](#), only one Electrical Propulsion Unit (EPU) is depicted. This is for simplification purposes as several motors can be required to ensure thrust/lift. In the case of potential shut-down of one of the electric engines, the thrust/lift should be managed by the remaining electric engines.

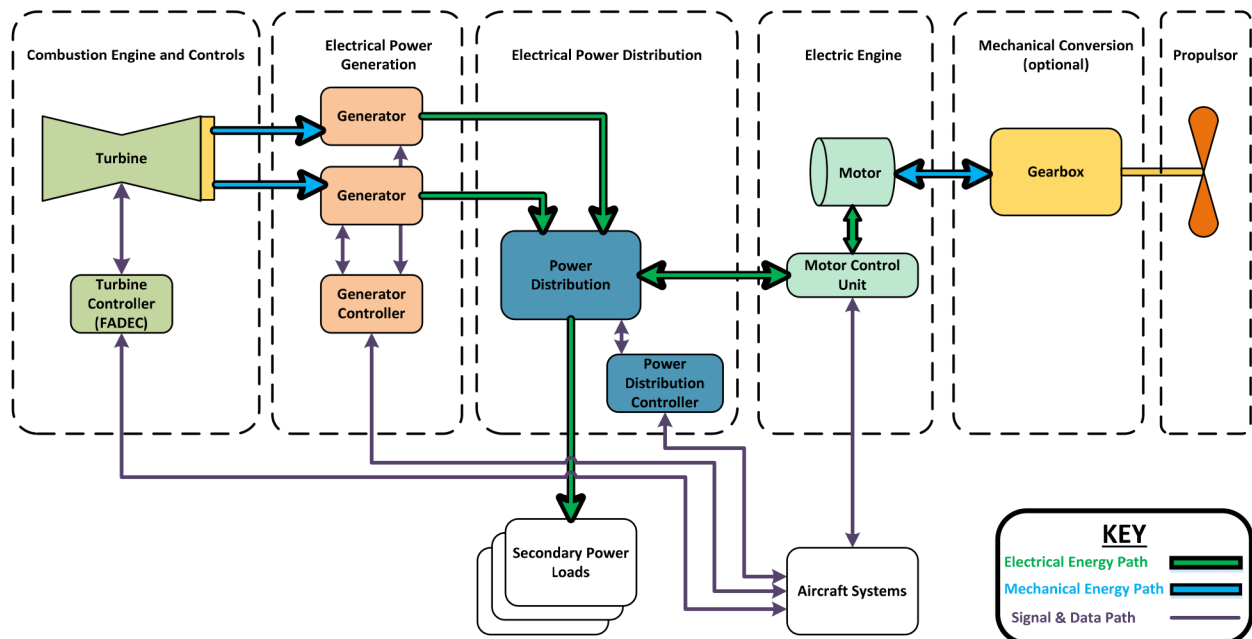


Figure 3 - Turboelectric propulsion architecture
 Reprinted with permission from AIR8678. © SAE International.