STANDARDIZATION GAP ANALYSIS

12 November 2024

AZEA WG-4 SG-3

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1. Executive Summary

This document is part of a sequence of studies of the AZEA WG04/SG03 “Standards” whose mission is to focus on the industry-wide structuring of standardization effort to support the certification of newly electric, hybrid-electric and hydrogen-powered aircrafts as well as the development of harmonized interoperable ground infrastructure, operations and supply chain solutions. In addition to the first report published in June 2023, which mapped the main existing committees and standards structured around these two main technologies, this document updates this previous standardization landscape and provides a gap analysis concerning standardization activities compared to awaited needs to support regulations specified in the new Specific Conditions (SC).

Indeed, authorities are elaborating an evolution in the regulatory framework to ensure and facilitate the safe deployment of disruptive technologies used for electric, hybrid-electric and hydrogen-powered aircrafts. Compared to previous Certification Specifications (CS) tailored to traditional technologies, development and publication of Performance Based Rules (PBR), which are non-prescriptive and technology agnostic, are promoted by authorities for the introduction of new propulsion systems. The expectations to demonstrate compliance to the PBR will be explained in Acceptable Means of Compliance (AMC), technology- and architecture-dependent, which may include references to industry standards. Moreover, EU R&D projects, thanks to their involvement in the early stages of a technology development, are identified as key enablers to bring new developments and recommendations to the rulemaking and standardization bodies for new rules or evolution of current rules stated in the PBR, and priorities.

This gap analysis is intended to be a support document for Standardization Development Organizations (SDO), authorities, industrial and governmental stakeholders. It gives for each main technology a clear mapping of the ongoing standardization activities or the one to be planned to support regulations at two levels: the aircraft and the system (including sub-system and components). The tables implemented in the following clauses are intended to be updated periodically.

This gap analysis highlights the following points:

- SDOs collaboration is essential to limit the risk of duplication and overlap (which is about to be the case for Electric and Hybrid-Electric Technologies and Aircraft at system level);
- Direct involvement and contribution of authorities is essential in the development of industry standards intended to be used as AMCs to facilitate compliance to regulation;

Concerning Electric and Hybrid-Electric Technologies and Aircraft:

- At system level: SC-E 19 provides the requirements and, therefore, a gap analysis of potential available industry standards for each requirement has been realized and it is available in Annex II. For hybrid-electric systems, the main gaps in standardization include performance metrics under various operational conditions, integration with existing aircraft systems, and establishing protocols for maintenance and safety.
- At aircraft level: it is expected that aircraft integration requirements and standard MOC will be developed iteratively, addressing one category after the other;

Concerning Hydrogen Technologies and Aircraft:

- At system level: there is no regulatory framework thus, it is not possible to assess the coverage by industry standards of MOC to regulation. Nevertheless, a list of standardization needs has been initiated to provide a first overview of the subfield which could be covered by an industry standard. For hydrogen propulsion, the primary gaps lie in storage and distribution infrastructure, fuel cell technology integration, and ensuring the safe handling and refueling processes.
- At aircraft level: currently the maturity of the technology is evolving and will require increased efforts in standardization work. Resources shall be used to work on standardization activities at the system level which is expected to be common to most aircraft categories and applications.

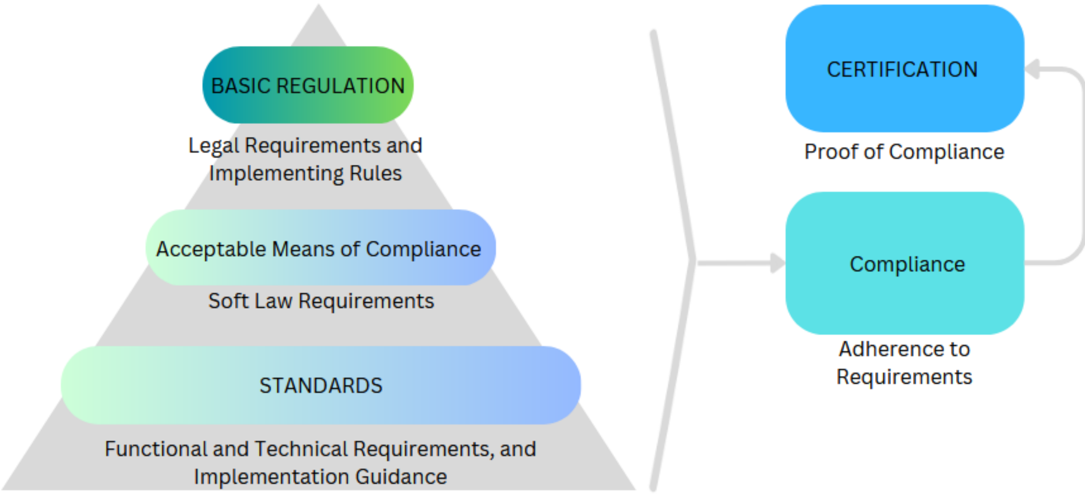
Concerning Airport Operations and Infrastructures: harmonized means of compliance will be implemented:

- For Airport design and operations: it is expected that ICAO will be the main source of data and information identifying gaps in standardization
- For Airport Infrastructure: a gap analysis will be realized through a coordination group within AZEA

2. Introduction

2.1. AZEA WG-4 Sub-group task

Intensifying environmental concerns are driving significant technological advancements in the area of hydrogen and electric aviation which require an evolution of the regulatory framework to ensure their safe deployment. To establish Acceptable Means of Compliance to this new regulatory framework, aviation authorities and governments refer to industry consensus standards that reflect state-of-the-art best practices. Industry Standardization activities therefore assume a crucial role in facilitating the certification of aircraft and engines based on these new technologies, their operation and the infrastructure necessary to support them.



Considering the amount and the variety of standardization needs and the limited resources available to address them, it is essential for the aviation industry to harmonize standardization activities and foster collaboration between the committees carrying them out. Additionally, increasing attention is being focused on the alignment of priorities and timeframes for the development of new standards.

Within AZEA WG-4, a dedicated subgroup is focusing on the industry-wide structuring of standardization effort. In a previous AZEA WG-4 deliverable published in June 2023, the subgroup described the standardization landscape, which consisted in a comprehensive mapping of existing standards and committees supporting electric, hybrid-electric and hydrogen-powered aircraft as well as ground infrastructure and operations.

This gap analysis builds on this mapping by identifying areas where new standards are needed. A future AZEA WG-4 publication will further complete this overview by proposing a comprehensive and structured set of recommendations to address gaps in standardization.

This gap analysis and roadmap are expected to be updated regularly to support OEMs, authorities and SDO in the establishment of their work programs and priorities. It will also help identify risks of overlap and duplication of efforts while identifying opportunities for collaboration.

The first document from WG-4 on the "Current Standardization Landscape" proposed a mapping of the main existing committees and standards structured around the two main technologies: electric/hybrid-electric technologies, and hydrogen technologies. This Standardization Gap Analysis proposes a detailed list of standardization needs for these two categories and identifies those that are already addressed by published or planned standards.

It is meant to be a living document with the intent to support all standardization stakeholders (OEMs, Authorities, SDOs…) to validate and consolidate roadmaps and priorities, identify risks of overlap/duplication and identify opportunities for collaboration. Through this document and future publications, AZEA WG-4 intends to produce and maintain this reference data and make it available to the industry.

2.2. Introduction to Hybrid-Electric and Hydrogen Aircraft Regulation, Certification and Standards.

The introduction of electric, hybrid-electric and hydrogen-based propulsion technologies has the potential to significantly reduce aviation's carbon footprint. The development of these novel technologies and their integration into a wide variety of engine and aircraft architectures are progressing at a rapid pace, with new concepts emerging on a regular basis. Within this context, legacy design and operational rules and practices, many of which are tailored to traditional technologies and aircraft architectures, are not always adaptable to novel technologies over such a range of applications.

The level of complexity induced by such novelty and variety will only be manageable if a harmonized framework of regulation and common industry practices and solutions is developed and deployed. In particular, one of the key early challenges for industry and aviation authorities is the development of a certification framework for electric, hybrid-electric and hydrogen-powered aircraft that provides sufficient flexibility to foster innovation while clearly identifying authority expectations to demonstrate compliance. Likewise, these aircraft can only enter service if harmonized interoperable ground infrastructure, operations and supply chain solutions are developed and introduced. Industry, aviation authorities and local, regional, national and European government are expected to largely rely on industry consensus standards to achieve this harmonization.

The development of regulations and new infrastructure to support such disruptive aircraft configurations is a key complementary issue to be addressed in order to realize the market potential. New means of compliance, new global certification approaches such as virtual testing and demonstration, or dedicated rules will be required to certify a new hydrogen and hybrid- electrical aircraft.

3. Standards Means and Methods of Compliance

One of the key enablers for the introduction of novel propulsion technology aircraft is the development of a regulatory framework supporting these technologies as well as a set of industry standards that may be relied upon to demonstrate compliance to this regulation. Authorities are faced with the challenge of introducing rules that ensure an equivalent level of safety compared to legacy technology aircraft without impeding on innovation. To achieve this, they are relying on performance-based rules (PBR).

The following paragraphs further introduce the notion of PBR. They also provide an overview of ongoing European-based research activities supporting the development of regulatory frameworks. Finally, they highlight the main challenges faced by industry stakeholders to effectively develop a comprehensive portfolio of standards that may be referenced by authorities as acceptable means and methods of compliance to regulation.

3.1. Introduction to Performance-Based Rules

Over time, prescriptive engine and aircraft certification rules specifically tailored to the technologies and architectures, which were implemented in the vast majority of aircraft, have been introduced and enforced. This approach presented the advantage of setting clear criteria for compliance. However, it is poorly adapted to an environment where new technologies, new aircraft concepts and new compliance demonstration strategies departing from the original architecture for which these rules were made for, are being proposed on a regular basis.

Authorities have recognized this and are pursuing the development and publication of performance-based rules (PBR). This shift started with CS-23 Amendment 5, applicable to General Aviation aircraft, which was developed to implement a PBR approach applicable to legacy technology aircraft. It has since been implemented in early Special Conditions applicable to novel technologies and aircraft concepts such as SC E-19 on Electric and Hybrid Propulsion Systems and SC-VTOL on Vertical Take-Off and Landing aircraft. Likewise, the rules for operation in the European airspace are shifting to performance-based rules with NPA 2022-11, which approves the ongoing changes in EU OPS 965/2012, being an example of the reliance on PBR to enable the introduction of new technology on the market.

While PBR provide the flexibility required to accommodate the wide variety of electric, hybrid-electric and hydrogen-based engine and aircraft concepts being developed, expectations to demonstrate compliance to these rules may not be self-evident. To clarify this, authorities are increasingly relaying on standards and are developing Guidance Material (GM) and Acceptable Means of Compliance (AMC).

Guidance Material (GM) is non-binding explanatory and interpretation material on how to achieve the requirements contained in the Basic Regulation, the Implementation Rules, the AMCs and the CSs. Acceptable Means of Compliance outline methods or processes accepted by authorities to demonstrate adherence to rules. This may include references to industry standards, adherence to which is considered by authorities as being appropriate to demonstrate compliance. However, Alternate Means of Compliance can be proposed if they can be shown to meet the intent of the rule.

In addition to the shift towards PBR, authorities and industry are faced with the risk of misalignment of certification and airworthiness rules and means of compliance at an international level. Due to constraints in their legal frameworks, EASA, the FAA, ANAC and Transport Canada have not yet been able to fully harmonize the sets of rules applicable to electric, hybrid-electric and hydrogen systems and integration. Despite these limitations, they have clearly stated their intent to harmonize means and methods of compliance and expect to heavily rely on globally referenced standards to achieve this.

Standards are therefore expected to play an important role in shaping industry practices and ensuring a level playing field in the demonstration of compliance to existing and future regulation. The development of such standards will only be possible if the development effort is coordinated at industry level and if strong collaboration between industry and authorities is established within the working groups developing them.

3.1.1. Aviation authorities' involvement in industry standardization WGs

- Highlight top priorities as they have a unique view and in a unique position to identify common concerns and urgent areas.
- Publication phase: guide the WG with information and rational on how the standard fits authority's expectation.
- Referencing standards in AMC as Means of Compliance and GM.

Authority involvement in standardization working groups
Authorities direct involvement and contribution in working groups is essential in the development of industry standards intended to be used as AMCs to facilitate compliance to regulation.
SDOs collaboration is essential to ensure balanced representation of authorities in the development of industry standards.

3.2. R&D and Technology Development

The following section provides an overview of ongoing European-based research activities supporting the development of Hybrid-Electric and Hydrogen Aircraft and its regulatory frameworks.

In Europe, the Clean Aviation Joint Undertaking encompasses several programmes supporting research and innovation in the field of sustainable aviation.

Prior to the Clean Aviation programme, the Clean Sky 2 programme (2014-2024) aimed to develop cleaner air transport technologies to reduce CO2, NOx, and noise emissions by 20-30% compared to aircraft from 2014. It focused on integrating, demonstrating, and validating these technologies for early deployment.

The Clean Aviation programme (2021-2031) builds on this with three key initiatives aimed at enhancing energy efficiency and reducing emissions of future aircraft:

1. Hybrid Electric Regional Aircraft: this initiative focuses on developing and integrating novel hybrid-electric power systems, aiming to have a regional aircraft ready by 2035. This aircraft will feature hybrid-electric propulsion, supported by 100% drop-in fuels or hydrogen, reducing emissions by up to 90% and complying with ICAO noise rules.

2. Ultra-Efficient Short and Short-Medium Range Aircraft: this initiative targets short and medium-range aircraft needs by developing innovative aircraft architectures and ultra-efficient thermal propulsion systems to improve energy efficiency by 30% by 2035.

3. Hydrogen-Powered Aircraft: this initiative explores the use of hydrogen as a zero-carbon fuel, focusing on liquid hydrogen storage, fuel distribution, and propulsion systems. The goal is to mature and demonstrate these technologies for integration into future aircraft, ensuring performance, safety, and cost-effectiveness.

The CONCERTO project within Clean Aviation focuses on the certification of novel technologies. It aims to ensure that future regulatory frameworks do not impede innovation, by streamlining certification processes to bring new products to market quickly and safely. This project will develop regulatory material and compliance methods applicable to the three use cases studied by Clean Aviation, providing a digital framework for certification. As one of the outcomes, CONCERTO has defined a certification readiness level scale aiming to assess the future certifiability of an innovative concept of operation, business model, and product/system, while engaging progressively with aviation authorities to facilitate future shared oversight activities.

R&D projects are encouraged to bring new developments to the rulemaking and standardization bodies with EU-wide proposals and recommendations for new rules, evolution of current rules, and priorities. This is achieved by identifying standardization and regulatory gaps in the early stages of technology development. These should be funneled to the appropriate standards development working groups and incorporated into their standards in coordination with authorities.

Coordination between R&D and standardization efforts
R&D projects should coordinate with Standards Development Organizations (SDOs) to provide recommendations for the adaptation or development of standards targeting new technologies.

3.3. Stakes and Challenges

The following paragraph highlights the main challenges faced by industry stakeholders to effectively develop a comprehensive portfolio of standards that may be referenced by authorities as acceptable means and methods of compliance to regulation.

The large-scale development of industry consensus standards required to support the introduction of electric, hybrid-electric and hydrogen aircraft is unprecedented in the aviation industry and induces a number of challenges and risks. The development of a globally harmonized set of standards in a timely manner will only be possible if standardization efforts are organized and coordinated in a way that maximizes efficiency.

3.3.1. Industry Priorities and Maturity

As early applicants progress through various stages of electric, hybrid-electric and hydrogen-powered aircraft development and certification, OEM's and authorities' knowledge and understanding of technical challenges and the practices effective at addressing them is constantly improving. As a result, standardization priorities change on a regular basis, as does the industry's ability to reach consensus on best practices for a given topic.

An example of this challenge is the eagerness to develop standards which attempt to holistically address broad topics such as safety, certification or test and qualification. Working groups are often faced with the realization that the level of maturity of industry is such that consensus can only be reached on few targeted subsets of these broad topics. This may lead to delays or stalling of standardization efforts and divert groups of experts from working on other, higher priority topics which are ready to be addressed.

To mitigate this risk and focus standardization efforts on higher priority needs, working groups and standards development organizations should regularly update their roadmaps and ensure that document scopes and terms of reference are thoroughly validated to reflect industry priorities and maturity.

Inputs from authorities are helpful as they are in the best position to assess alignment of standard objectives with existing and planned regulation as well as highlighting common needs and trends across the industry.

The industry and authorities should also accept that in the short term, standards will be developed iteratively as maturity increases. SDO organizational and procedural frameworks should be adapted to efficiently support such frequent standard updates.

Finally, the ability of SDOs and working groups to effectively establish and address industry priorities is strongly dependent on the involvement of all key industry actors, and SDO procedural frameworks that ensure balanced representation and consensus. This requires proactive participation from these actors and SDO-supported collaboration between working groups to foster international harmonization.

Collaboration between SDOs and authorities is then a crucial aspect of ensuring that industry best practices remain current, relevant, and aligned with regulations. This is particularly important for standard referencing and the revision of standards.

SDO and working group roadmaps
Industry, SDOs and authorities should proactively participate in the development and maintenance of working group roadmaps to ensure that they are always consistent with top industry priorities.

Iterative development of standards
Industry, SDOs and authorities should ensure that their processes and practices accommodate regular updates of standards consistent with the continuous improvement of industry knowledge on novel technologies and their implementation.

3.3.2. Risks of Duplication or Overlap

The ecosystem of working groups involved in the development and publication of industry standards for aviation is large and complex. Legacy working groups are often focused on specific conventional technologies, systems or aircraft categories and may be restricted to experts from specific countries or regions. Several of these groups have recognized the need to address electric, hybrid-electric and hydrogen technologies and are incorporating this into their roadmaps. In addition, new groups specifically focused on novel technologies, systems and aircraft are being created.

This induces significant risks of overlap and duplication of efforts, which may in turn lead to the publication of competing standards. This may impair the industry's ability to develop a stable and consolidated international framework of practices supporting the certification and operation of novel aircraft.

In order to mitigate these risks, the industry should coordinate to achieve the following objectives:

- Promote global or international standards development to avoid regional divergence in practices.

- Promote collaboration between working groups to avoid competing efforts and ensure mutual recognition and complementarity of industry standards.
- Define and update working group scopes so that they are sufficiently precise to identify and manage risks of overlap and opportunities for collaboration between groups.
- Avoid the creation of new groups when existing groups have the expertise and industry representativeness to propose globally applicable standards on a given scope.
- Ensure proper document scoping to avoid risks of unintentional overlap and ensure early adherence to standard objectives by industry and authorities.

To achieve these goals, SDOs should facilitate and promote collaboration between groups or joint groups. They should also favor the harmonization of their processes to increase the efficiency of joint group publication development and publication.

Finally, SDOs and working groups should be able to rely on a common, publicly available set of informational resources to be aware of needs, activities, roadmaps and publications throughout the ecosystem. This document and future publications of AZEA WG-4 aim at addressing this need.

Promotion of international harmonization and collaboration
SDOs, industry and authorities should promote coordination and collaboration between standardization working groups to limit the risk of duplication and overlap.
AZEA WG4 should produce and maintain a repository of the standardization needs, and act as a watch tower regarding the duplication or overlap risks for the standards for Electric, Hybrid-Electric and Hydrogen Aircraft.

4. Standardization Gap Analysis for Electric, Hybrid-Electric and Hydrogen Aircraft

The standardization gap analysis detailed in the following chapters identifies standardization needs relevant to electric, hybrid-electric and hydrogen aircraft and associated airport operations and infrastructure. It is structured in three categories: electric/hybrid-electric aircraft, hydrogen aircraft and airport operations and infrastructure.

When possible, links between existing regulation and industry standards which may constitute means of compliance to this regulation are highlighted.

In addition to listing standards that have been published or are under development, the analysis identifies topics for which industry or authorities have identified opportunities and needs for standardization that are not yet being addressed. It also identifies the standardization working groups and committees expected to develop existing and future standards. Future issues of this gap analysis will introduce timeframes for the development of new standards.

The main intent of this gap analysis is to support OEMs, authorities and standardization working groups and committees to develop, validate and consolidate roadmaps and priorities, identify risks of overlap and duplication and identify opportunities for collaboration. As aircraft continue to be developed, certified and operated, it is foreseen that the needs and priorities for new standards will evolve on a regular basis. This gap analysis is expected to be updated periodically to reflect this.

4.1. Electric and Hybrid-Electric Technologies and Aircraft

Electric and hybrid-electric propulsion, as described in SC E-19, encompasses a wide range of technologies and architectures with various levels of novelty compared to traditional aircraft propulsion systems. The common feature in all of these solutions is the partial or complete reliance on electric power/energy to produce lift, thrust or power for flight.

Some technological novelties are common to most of these applications. Examples include higher voltages and levels of electrical power, higher electric/electronic system heat dissipation and use of novel semiconductor technologies. In addition to technological novelties, architectural novelties are being explored, some of which significantly depart from traditional aircraft architectures. As a result, new functions are being introduced, existing functions are being implemented in new ways and new system interfaces and interdependencies are being created.

As described in §3 of this document, authorities are addressing this variety by developing and publishing performance-based rules which are intended to be applicable to wide ranges of products. These rules must be complemented by means and methods of compliance which will typically be technology- and architecture-dependent. Industry standards whose intent is to propose means and methods of compliance to regulation are therefore expected to be focused on specific technologies, engine and/or aircraft types.

The first standard developments have focused on topics that are common to most early applications, often limiting their scope to fully electric engines. More recently, some aircraft integration aspects specific to general aviation and eVTOL aircraft have been addressed to cover the first electric and hybrid aircraft projects which fit in these categories. While engine-level standards may be applicable to multiple types and categories of aircraft, aircraft-level standards are expected to focus on specific categories.

4.1.1. Current Standardization Landscape

The standardization ecosystem supporting electric and hybrid-electric propulsion is generally mature, with several committees working on the topic. Table 2 provides an overview of these committees.

Standardisation Organization	WG/COMMITTEE		WG/COMMITTEE Description
EUROCAE	WG-113 Hybrid Electric Propulsion		The aviation industry is witnessing a revolution that will see integration of more electricity to power vehicles. Studies into the electrification of aircraft propulsion revealed the potential of reducing carbon footprint by 50% between 2005 and 2050 – supporting ACARE goals. This WG aims to address the regulatory framework and means of compliance for these new architectures. The WG developed a report on standardization needs for EHPS and currently is working on Guidance material for endurance and durability substantiation of EHPS
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)		WG-112 is specifically tasked to develop in a timely manner all the standards necessary to support the Special Condition on Vertical Take-Off and Landing (VTOL) aircraft in close cooperation with EASA.Work is organised around 9 technical Sub-groups. Current activities include: batteries, Hi-voltage distribution, fire management, rotorburst, handling qualities, performance, energy & flight information, security and safety processes, seats for AAM aircraft, electromagnetic (EM) hazards for AAM/UAM, vertiport operations, charging infrastructure.
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)	WG-112 SG-1 Electrical	WG-112 SG-1 will develop standards for VTOL-specific aspects of electrical systems
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)	WG-112 SG-2 Lift-Thrust	WG-112 SG-2 develops for VTOL-specific aspects for thrust / lift systems
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)	WG-112 SG-3 Safety	WG-112 SG-3 develops standards for VTOL-specific safety aspects
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)	WG-112 SG-4 Flight	WG-112 SG-4 develops standards for VTOL-specific aspects of flight
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)	WG-112 SG-5 Ground	WG-112 SG-5 develops standards for VTOL-specific aspects of ground infrastructure and airports
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)	WG-112 SG-6 Avionics	WG-112 SG-6 develops standards for VTOL-specific aspects of Avionics
EUROCAE	WG-112 Vertical Take Off and Landing (VTOL)	WG-112 SG-9 Electromagnetic Hazards	WG-112 SG-9 will develop standards for VTOL-specific aspects of EM hazards.
EUROCAE	WG-116 High Voltage Systems and Components in Aviation		The WG is tasked to define new standards for high voltage systems and components in aircraft. These standards are needed for the industry and the certification authorities to develop and certify new designs for electrical and hybrid aircraft, where electrical voltages will be much higher than the current standards. Current activities focus on Interface Characteristics and Power Quality of Aircraft High Voltage Propulsive Electrical Systems, Risk Mitigation at EWIS and Human Safety Level and Aging mechanisms of electrical insulation (this last activity joint with SAE AE-11)

Table 2. Part I. Main committees focused on electric and electric-hybrid propulsion aircraft.

Standardisation Organization	WG/COMMITTEE	WG/COMMITTEE Description
SAE	AE-7D Aircraft Energy Storage and Charging Committee	The AE-7D Aircraft Energy Storage and Charging Committee is responsible for creating and maintaining technical reports for battery energy storage, distribution, and charging. It covers standardization in charging plugs, something which will concerns charging standards at both the side of the airport and the aircraft.
	AE-9 Electrical Materials Committee	SAE AE-9 has the responsibility to develop and maintain SAE Technical Reports (including Standards and Material Specifications) for use in aircraft and engine electrical and avionic systems, including hardware items. The SAE AE-9 Committee is developing and publishing SAE Technical Reports (AIR's, ARP's, and AS's) on this topics.
	AE-10 High Voltage Committee	The AE-10 Committee is working on managing Higher Voltages in Aerospace Electrical Systems, safety and reliability, Insulation Monitoring Devices, Electric Load Analysis and Power Source Capacity Planning, while avoiding duplication. The Committee set prioritization and associated timescales, manages standards' deliverables per the roadmap defined by the HVCC, coordinates with other SAE standards activities as necessary; and establishes relevant collaboration with other SDOs (EUROCAE WG-112, WG-116, ASD-STAN, etc.) as appropriate.
	AE-11 Aging Models for Electrical Insulation in Hi-Enrgy Sys	This committee aims to identify the failure mechanisms of electrical insulation components, and analyze the resulting impacts on their physical properties, in order to define a multi-physics (electrical and thermal) model of the aging phenomenon. Joint with WG-116 EUROCAE
	E-36 Electronic Engine Controls Committee	Areas of interest include, but not be limited to, the design, installation, operation and maintenance of engine control system components including metering components and actuators and the interface and communication methods for (A) Cockpit Displays, (B) Flight Control, Diagnostic and Health Monitoring Systems. Coordination with other SAE committees will occur to minimize redundant activities within the organization and maximize the benefit of additional recommendations and standards.
	E-40 Electrified Propulsion Committee	The SAE E-40 Committee develops technical reports (Aerospace Standards, Aerospace Recommended Practices and Information Reports) covering electrified propulsion for aircraft with a payload weight above 150lb / 70KG. The committee will recommend standardized nomenclature, define applicable terms and fundamental architectures, and address considerations for performance (including endurance), safety, high voltage/high power, aircraft integration, components and interfaces within and between propulsion system and aircraft equipment.
	AGE-3 Aircraft Ground Support Equipment Committee	AGE-3 addresses all aspects of airport, ground support equipment and associated systems that interface or require compatibility with the aircraft. The objectives of the Committee are: a) Develop and maintain technical standards, specifications and reports related to aircraft ground servicing and in particular to: Airport Ground Support Equipment (GSE) - Aircraft to GSE interface - GSE operation, maintenance and operator training - Airport facilities and systems that have a direct relationship to and interface with GSE - GSE environment related issues, including noise and emissions.

Table 2. Part II. Main committees focused on electric and electric-hybrid propulsion aircraft.

Standardisation Organization	WG/COMMITTEE	WG/COMMITTEE Description
ASTM	F39 - Aircraft Systems	To address growing concerns regarding aircraft electrical wiring systems, the US FAA's Small Airplane Directorate initiated a voluntary consensus standards effort to develop standards addressing general aviation electrical wiring systems. Due to objections regarding the utilization of generic guidance (such as FAA Advisory Circular 43.13-1B) as the certification basis for design and modification, Committee F39 is designed to develop standards for electrical wiring system design, fabrication, modification, inspection and maintenance procedures and processes.
	F44 - General Aviation Aircraft	This Committee addresses issues related to design and construction, systems and performance, quality acceptance tests, and safety monitoring for general aviation aircraft (also known as Part 23) that is less than 19,000 pounds and 12 passengers.Through the establishment of a Part 23 Aviation Rulemaking Committee (ARC), industry expressed an interest in evolving Part 23 regulations into a more performance based document, reliant on standards for the design and performance of aircraft, in order to leverage all the benefits that referencing standards has to offer. Ultimately, the desire is to reduce the regulatory burden on the industry (and therefore the cost of the aircraft) and leverage standards to allow technology to be readily updated in a streamlined certification process where appropriate.
	F37 - Light sport a/c	Working in a Standard Practice for Design and Manufacture of Electric Propulsion Units for Light Sport Aircraft covering minimum requirements for the design and manufacture of Electric Propulsion Units (EPU) for light sport aircraft, VFR use.
ASD-STAN	D02 Electrical	The expansive scope of Domain D02 encompasses the standardization of electric cables, stripping tools, connectors, contacts, accessories, crimping tools, protection systems (including circuit breakers), optical components, and various other electrical elements essential to aerospace applications. D02 has Subcommittees working on: D02/WG01 “Electrical Network”,D02/WG02 “Cables & Stripping Tools", D02/WG03 “Elements of Connection (Connectors, Contacts, Rear Accessories, Crimping Tools)", D02/WG04 “Relays, Switches, Push-Buttons”, D02/WG05 “Protection Devices”, D02/WG06 “Exterior and cockpit lighting (Lamps, LED, etc.)”, D02/WG08 “Installation technologies”, D02/WG10 “Optical Components”, and D02/WG12 “Modular & Open Avionics Architecture (MOAA)”.
RTCA	SC-135 Environmental Testing	SC-135 is responsible for maintaining the documents which define the standard for testing commercial avionics equipment in various environmental and electromagnetic conditions. Along with the testing requirements, the committee also maintains a user’s guide to assist in understanding the complexities in the test requirements.
	SC-225 Rechargeable Lithium Batteries and Battery Systems	RTCA SC-225 was formed to provide certification guidance for lithium batteries and battery systems that are permanently installed in aircraft
ISO	TC20/SC-1 Aerospace electrical requirements	ISO/TC20/SC1 engages in the preparation of international standards related to the generation, control and distribution of electrical energy, including associated materials and components, for civil aircraft, and aerospace application.

Table 2. Part III. Main committees focused on electric and electric-hybrid propulsion aircraft.

The descriptions of the scopes of the committees in table 2 highlight several risks of overlap and duplication. Three key risks are detailed below. In addition to these specific risks, there is a general concern that the existence of multiple working groups covering similar topics will dilute resources and expertise even when coordination is in place to avoid overlap. In particular, some organizations and authorities do not have the resources to attend virtual and physical meetings for multiple working groups. To limit this risk, SDOs and working groups should favor either joint operation or the organization of joint meetings involving all industry experts in a single forum.

Rationalization of standardization work
Industry and SDOs should collaborate and rationalize standardization work to favor better support from industry actors with limited resources, in particular joint virtual/physical meting should be organized involving all industry experts.

Electric/Hybrid-Electric Propulsion:

Two committees with very similar scopes exist: EUROCAE WG-113 and SAE E-40. These committees recently agreed on a collaboration framework which is designed to ensure that topics will either be addressed by one committee only or be addressed by a joint standard.

High-Voltages:

Several legacy committees across multiple SDOs have historically addressed electrical component and system design and integration. Some of these groups have expanded their scope to high-voltage propulsion applications. In parallel, new groups have been created to specifically address high voltages. This results in a complex ecosystem with only limited, ad hoc collaboration and coordination, with a significant risk of overlap, duplication and diverging standards.

Batteries:

In addition to battery-focused working groups, several system or aircraft integration-focused committees have been including battery considerations in their standards with only limited, ad hoc collaboration and coordination. This also induces a significant risk of overlap, duplication and diverging standards.

4.1.2. Gap Analysis

The introduction of electric and hybrid-electric propulsion may induce a higher level of integration between the propulsion system and the aircraft compared to legacy applications. As a result, it may be more difficult to distinguish propulsion system and aircraft activities. Despite this shift, early standardization efforts have largely been structured by the historical boundary between engine and aircraft certification. The gap analysis provided in the following chapters is therefore broken down into two levels: system, subsystem and component level – primarily focused on the propulsion system – and aircraft integration level. This also matches the most common breakdown of certification regulation, allowing the direct identification of links between rules and candidate standard means and methods of compliance.

The starting point for the development of this gap analysis was an assessment performed by EASA of coverage by industry standards of SC E-19 requirements. The results of this assessment were shared with industry as part of a webinar during which EASA highlighted the standards, published or under development, which it expects to be candidate means of compliance to E-19 requirements. EASA also highlighted the main gaps in this coverage.

Section 4.1.2.1 builds on this initial assessment, providing an updated mapping of ongoing standards development activities, gaps in coverage of SC-E-19 and an indicator of priorities based on authority and industry feedback.

Section 4.2.1.2 provides an overview of the status of aircraft integration standards. This is not structured based on aircraft-level regulation as there is significant disparity in the level of maturity of sets of rules applicable to various aircraft categories.

4.1.2.1. System, Sub-System and Component Level

Table 4 provides a summary of the level of coverage of each SC E-19 requirement by industry standards proposing means of compliance. This includes both published standards and standards under development, the main intent being to highlight rules that are not being addressed at the time of publication of this document. A high-level assessment of coverage is indicated using the following color coding:

Status of coverage of MoCs by standards	Color Code
No need for standard MoCs identified	Not Included in Summary Table
Published standards cover expressed needs or identified gaps are being addressed	
Standards are currently under development	
Standards are in WG roadmaps but not yet under development	
Standards are not in WG roadmaps	

Summary Gap Analysis

Requirement	Title	Gaps and Comments
EHPS.20	**EHPS Configuration**	No standardized guidance to certify the engine as part of the aircraft
EHPS.230	**Vibration Survey**	Need to cover Electrical Rotor Insulation in future standardization activities.
EHPS.240/250	**Rotating Parts Containment**	Need to develop a standard, detailed method to demonstrate containment of rotating parts in case of rotor failure.
EHPS.300	**Fuel System**	Depending on the possible expansion of the scope of SC E-19 to hydrogen, H2 fuel systems would have to be covered (refer to §4.2 of this document for details).
EHPS.310	**Lubrication System**	Need identified for the development of standards for lubricants applicable to gearbox lubrication, bearings lubrication and liquid cooling.
EHPS.320	**Cooling System**	Need to further develop and harmonize a method for cooling systems demonstration for EHPS. Priority to consider flammability and electric conductivity of the lubrication system.
EHPS.380	**Propulsion Battery**	Missing guidance for energy reserves for small aircraft. Also need guidance to bridge the gap between CS-23 and E-19, as CS-23 does not address propulsion batteries.
EHPS.480	**EHPS Specific Operation**	Need to further develop ratings on temperature and substantiation of the representativeness of the propeller
EHPS.100	**Fire Protection**	New activity WG-112/WG113 being launched for Fire Protection standard for Hybrid Electric aircraft. Priority 1 for EASA to produce MOC covering windmilling conditions after short circuit.
EHPS.290	**Bird, Hail Strike and Impact of Foreign Matter**	New activity is being launched E-40/WG-113 to address the topic at engine level.
EHPS.370	**Electrical Power Generation, Distribution and Wirings**	Need to expand existing guidance on a number of topics for application to high voltage systems up to 1500VDC. Also need to define standard approaches to implement proportionality to the application of EWIS rules.
EHPS.430	**Durability Demonstration**	Durability demonstration is being addressed by WG-113 in coordination with E-40.

EHPS.15	**Terminology**	Missing definitions
EHPS.30	**Instructions for Installation and Operation of the EHPS**	Need to define standards sets of data and information to be included in an EHPS Installation and Operational Manual.
EHPS.40	**Ratings and Operating Limitations**	New needs are driven by the novelty of distributed propulsion introduction.
EHPS.50	**Materials**	Continue coordination between SAE AE-10 and EUROCAE WG-116 to avoid duplication of efforts.
EHPS.80	**Safety Assessment, Reliability, LOPC**	Need to further work on (1) Electric engine control system architecture and reliability (2) Energy Storage integration and its interactions with the EHPS and the Aircraft
EHPS.420	**Endurance Demonstration**	Endurance Demonstration addressed in ED-321 published by EUROCAE for Class 1 and 2 aircraft under CS-23. Future industry developments and alignment to be included in the next revision of this Gap Analysis addressing CS-25 gaps.

Table 3. Summary of coverage of MoC to SC E-19 requirements by industry standards

The full Gap Analysis is provided in Annex 1 and includes all industry standards identified for each of the EHPS requirements.

4.1.2.2. Aircraft Level

Historically, certification requirements have been broken down into aircraft requirements (CS-2x), engine requirements (CS-E) and propeller requirements when applicable (CS-P). Each of these products was required to obtain its own type certificate. In parallel to the introduction of SC E-19, EASA has proposed a more flexible approach for certification, allowing these systems to be certified separately or as part of the aircraft.

Irrespective of the certification path, the certification requirements breakdown remains structured around the three legacy perimeters. At aircraft integration level, only SC-VTOL includes rules designed to accommodate EHPS integration. CS-23 Amendment 5, whose rules are performance-based, may also be adequate for EHPS integration. Other CS-2x regulations include prescriptive requirements specific to legacy technologies and will therefore require updates to accommodate EHPS integration.

The integration and installation of EHPS is dependent on each product category. Unlike SC E-19, whose applicability covers most aircraft categories, aircraft-level rules may therefore vary depending on the category.

It is therefore expected that aircraft integration requirements and standard means of compliance will be developed iteratively, addressing one category after the other as enough projects reach maturity. Early projects are being developed in the smaller aircraft (electric sailplanes, light sport aircraft and level 1 and 2 CS-23) and eVTOL spaces. The learnings from these projects are expected to feed rulemaking and standardization activities for other aircraft categories.

Within this context, early standards addressing aircraft-level considerations are expected to address three overarching needs:

- To identify the main safety challenges specific to the integration of these novel system
- To propose guidance on how to best address these challenges,
- To propose guidance on how to fulfil the intent of basic regulation (including general airworthiness, design and product organization, etc.).

It is expected that standards which address these overarching needs will be appropriate to address existing and future regulation applicable to EHPS integration.

At the time of release of this document, the volume of standardization activities focused on aircraft integration has been limited, with two working groups producing the majority of such standards:

- EUROCAE WG-112 focused on eVTOL
- ASTM F44 focused on general aviation and eVTOL

For all of the reasons detailed above, it is difficult to perform a comprehensive mapping of needs or gap analysis focused on aircraft integration. It is expected that future releases of this document will be able to provide more detail.

4.2. Hydrogen Technologies and Aircraft

The introduction of hydrogen-based aircraft propulsion technologies may induce significant and wide-ranging impacts on aircraft architectures and systems as well as introducing new risks and threats specific to gaseous and liquid hydrogen. For many of these novelties, reliance on legacy jet-fuel-based solutions and practices may not be appropriate. Likewise, the adaptation of hydrogen-specific practices from other industries and applications may not be compatible with aircraft's specific integration and operational constraints and objectives. As a result, the list of aviation-specific standards to be developed to support the introduction of hydrogen aircraft is large and is expected to evolve in the coming years. The following chapters provide a global view of these needs and their coverage by ongoing standardization efforts at the time of publication of this document.

4.2.1. Current Standardization Landscape

Table 5 provides an overview of the committees involved in the development of hydrogen standards for aviation.

Standardisation Organization	WG/COMMITTEE	WG/COMMITTEE Description	Aviation Application	Hydrogen
EUROCAE/SAE	WG-80/AE-7F Hydrogen Fuel Cells	WG-80 was established jointly with AE-7F to develop guidelines and collect best practices to support qualification and certification of Hydrogen Fuel Cell Systems in the various intended applications for aircraft applications.The Hydrogen Fuel Cell activity is part of the more electrical aircraft strategy. It is looking into hydrogen fuel cell technology airborne use cases and certification objectives. The objective is to look into recommendations, to collect best practices, and to develop guidelines. Performance requirements such as power and reliability are outside the scope of this working group.	x	x
	AE-5CH Hydrogen Airport Taskgroup	SAE AE-5CH has the responsibility for hydrogen as a fuel at the airport, jointly with EUROCAE WG-80. The objective is to develop standardization for hydrogen in aerospace and other aspects at the airport such as fueling, transport and storage. Harmonization with existing SAE Standards efforts (including SAE, EUROCAE, etc.) and Codes (such as NFPA, etc.) will be a priority.	x	x
SAE	AE-5C Aviation Ground Fueling Systems Committee	Has responsibility for the resolution of problems in either design or service usage of aerospace fuel, oil and oxidizer systems, their components such as valves, pumps, couplings, fuel cells, quantity and flow gages, and tanks, and related problems as presure surger, icing, electrification, and safety. Develops standards addressing fuel, oil and oxidizer systems.	x	x
ASTM	D03 on Gaseous Fuels	D03 has 7 technical subcommittees working over these standards. These standards have and continue to play a preeminent role in the gaseous fuels (natural gas) industry and address issues relating to collection and measurement of gaseous fuel samples, determination of heating value and relative density of gaseous fuels, determination of special constituents of gaseous fuels, analysis of chemical composition of gaseous fuels, and thermophysical properties.	x	x
	F38.01 Airworthiness on Unmanned Aircraft Systems	This Committee addresses issues related to design, performance, quality acceptance tests, and safety monitoring for unmanned air vehicle systems. Working particularly on developing new specifications for aviation hydrogen fuels.	x	x

Table 4. Main WG/Committees focused on hydrogen in aviation.

4.2.2. Gap Analysis

At the time of publication of this document, there is no regulatory framework for hydrogen. It is therefore not possible to assess the coverage by industry standards of means of compliance to regulation. Future versions of this report are expected to provide this overview once initial sets of rules are published.

In the absence of a regulatory framework, AZEA WG-4 SG-3 has established a list of standardization needs based on an industry consensus perception of novelties, challenges and risks inherent to hydrogen, hydrogen technologies and their application to aviation. The following inputs were considered to establish this list:

- Content and recommendations from published standards and authority publications such as the AIAA G-095A – FAA ESD ARC report
- Roadmaps and suggestions from hydrogen-focused standardization working groups
- Needs expressed by AZEA membership

Hydrogen-based propulsion technologies differ fundamentally from conventional and electric or hybrid-electric propulsion systems in design, limitations, and operational philosophy, presenting unique challenges. Some of the key differences include:

- Fuel: the basic characteristics of H2, either in gaseous or liquid phase, differ significantly from conventional fuel.
- Fuel Cells: the application of this technology to aircraft propulsion is addressed neither by regulation nor by standards.
- Hydrogen Storage and Distribution: the design, safety, and integration of hydrogen storage and distribution structures and systems differ significantly from conventional fuel systems, requiring new standard practices covering a wide range of topics such as design, manufacturing, maintenance and safety.
- Fire and Explosion: the flammability characteristics of hydrogen are significantly different than those of conventional jet fuel, requiring new standard practices covering topics such as flame characterization and fire and explosion prevention and protection, including in emergency landing conditions.

Authorities have started preliminary work which should eventually lead to the development and publication of hydrogen-focused special conditions. In parallel, AZEA WG-4 SG-2 is developing recommendations for potential certification pathways for hydrogen propulsion systems and hydrogen aircraft. These and other industry activities are expected to spawn a more comprehensive regulatory framework applicable to hydrogen. Once sets of rules become available, the structure of this standardization gap analysis will be modified to assess coverage of certification requirements with a similar approach to §4.1.2 of this document.

4.2.2.1. System, Sub-System and Component Level

Table 6 provides a summary of early standardization activities focused on the use of hydrogen for aircraft propulsion. These developments are initial steppingstones covering topics that are expected to be relevant to the majority of applications regardless of the aircraft category.

Document Project	Working Group	Objective
DP003 / AS6679 – Liquid Hydrogen Storage and Distribution	EUROCAE WG-80 / SAE AE-7F	Identify needs and challenges specific to liquid and gaseous hydrogen storage and distribution system design, installation, testing, safety, certification and maintenance
DP005 / AS7373 – Gaseous Hydrogen Storage and Distribution		
DP006 / AS7141 – Fuel Cells for Propulsion	EUROCAE WG-80 / SAE AE-7F	Identify needs and challenges specific to fuel cells dedicated to aircraft propulsion relative to design, installation, testing, safety, certification and maintenance
AIR8466 – Hydrogen Fueling Stations for Airports	SAE AE-5CH / EUROCAE WG-80	Identify needs and challenges specific to aircraft hydrogen refueling in both liquid and gaseous phases.
WK85474 – Specification for Aviation Hydrogen Fuels	ASTM D03	Initial specification for aircraft hydrogen fuel properties

Table 5. Early standardization activities on hydrogen for aviation

In addition to these early developments, a wide range of topics have been identified by industry as requiring standard industry consensus guidance. These topics are summarized in table 7. A more comprehensive list of needs is included in Appendix 3.

It is expected that many of the standards addressing the topics in table 7 may become candidate means of compliance to future regulation. Future issues of this document will assess coverage of this regulation by published and planned standards.

Area	Topic	Subtopic
Engine and Aircraft Systems & Components	On-Board Storage & Distribution	Tanks
		Tank emptying/venting
		Distribution system purging & inerting
		Foreign Object Debris
		Electrical bonding
		Fuel temperature conditioning (heat exchangers, etc.)
		Pipes
		Sealings & connections
		Protection vs excessive pressure at fuel system level
	H2/LH2 Equipment & Components	Design rules & practices for electrical equipment & components located in H2 leakage zones
		LH2 pumps
		GH2 compressor
		LH2 vaporizer
		Heat exchangers
		Valves
		Filters
		H2 Fuel Flow measurement
		Equipment qualification & environmental tests
	H2 Combustion Engines	Architecture definitions
		H2 Gas Turbines
		H2 Piston Engines

		Engine H2 Fuel System Purging & Intertization
		Control system
		Engine ingestion
		Endurance and durability
	Fuel Cells	Electrical Hazards
		Performance
		Environmental Tests
		Safety
		Aging and durability
		Fuel & air contamination
		Transport and storage
		Production acceptance tests (tests performed on every unit produced)
		Cooling
		Modeling and modeling tools (power management prediction, performance, etc.)
	Materials	H2 tolerance of materials (including corrosion & embrittlement)
		Tolerance of materials to LH2 and other cryogenic liquids/gases
	Integration	Aircraft integration of electrical and H2 systems
	Leak & Fire/Explosion Detection & Accommodation	H2 sensors (detecting the presence of gaseous H2 in a given location)
		Leak accommodation (ventilation, etc.)
		Zoning (Fire, explosion, asphyxiation & cryogenic risks)
		Fire & explosion prevention & protection
		H2 releases (assessment and control of consequences of H2 release, etc.)
		Firewalls
	Crashworthiness	Flare off/emptying of storage tanks after incident
		Crash survivability
Fuels	Fuel characteristics	LH2/GH2
		Ammonia, methanol & LNG as fuels for aviation
		Alternative carriers (LOHC/LIHC, metalhybride)
Ground Operations	Refueling	Fuel quality assurance at refueling point (including testing)
		Fuel quantity measurement/metering at refueling point
		Interface between refueling system and aircraft
		Refueling system materials & hoses
		Refueling system/vehicle performance
		Refueling procedure
	Maintenance	Line maintenance
		Shop maintenance
	Aircraft parking/storage	Aircraft dormancy (overnight parking)
		Aircraft dormancy (> 1 day)
	Emergency Response	Emergency first response
		Flaring & cryogenic risks

Markings	Markings	
Flight Operations		Flight & cabin crew training
		Pre-flight inspections
Airport Infrastructure	Airport H2 Production	Electrolysis
		Gasification
		Purification & quality control
	Airport H2 Storage	Liquefaction
		Gaseous or liquid storage
		Alternative carriers (LOHC/LIHC, metalhybride)
	Airport H2 Distribution	Hydrant system
		Transfer tanks
Sustainability, Origin & Atmospheric Emissions	Definition of wheel-to-well carbon footprint measurement, GHG emissions saving and KPI	
	Guarantee of origin of delivered gas	
	H2 release	Emergency & nominal (expected leaks, venting) release
	H2 Combustion Emissions	NOx and possibly other types of emissions
	Contrails	
Personnel Training		

Table 6. List of standardization needs for hydrogen propulsion aircraft

As there are currently no published aviation-focused hydrogen standards, table 7 can be considered as a list of gaps to be addressed in the coming years. To effectively and efficiently address these needs, some more detailed roadmaps will have to be developed, outlining the steps required to create the necessary standards and defining priorities based on the most urgent industry needs. As detailed in §3, close collaboration between industry stakeholders and regulatory authorities will be essential to ensure that standards fully address expectations for means of compliance and that they are developed according to industry priorities. Moreover, standards will have to be reviewed and updated iteratively to align with technological novelty, innovations and growing industry maturity in their application to aircraft propulsion.

4.2.2.2. Aircraft Level

Early standardization efforts are focused on technology and system-specific considerations which are expected to be common to most aircraft categories and applications. This is expected to be industry's main focus until a sufficient level of maturity on those topics is reached. From then on, it is expected that industry will address aircraft integration considerations on a category-by-category basis similarly to electric and hybrid-electric propulsion.

It is expected that several challenges applicable to aircraft integration of hydrogen propulsion systems will be similar to those encountered with electric and hybrid-electric propulsion systems. This includes challenges related to efficiency, reliability, and integration within the overall aircraft design.

Table 7 includes topics that span both system and component activities and aircraft integration activities. A more detailed breakdown of these topics into these two levels of integration will be possible once initial standards have identified key challenges and proposed general approaches to addressing them.

4.3. Airport Operations and Infrastructure

Airports are complex systems which require significant anticipation when considering changes to infrastructure and procedures to support aircraft operations. The operation of electric, hybrid-electric and hydrogen aircraft will require airport adaptations driven by technical needs and new or updated certification requirements and regulations. Reliance on standards applicable to airport infrastructure and ground operations would provide harmonized means of compliance enabling a global transition in a safe and efficient manner.

Within this context, it is expected that two different sets of standards applicable to airports will be developed:

- Aerodrome design and operations: these standards are expected to be specific to the aviation domain and adopted worldwide through globally recognized resources such as ICAO Annexes (including SARPS, EU regulations and EASA ED decisions, and FAA Advisory Circulars). Work on this topic has already started within the ICAO ADOP (Aerodrome Operations Panel) to define an Airport Concept of Operations for Sustainable Alternative Fuels, and identify existing ICAO reference material to be updated and/or edited.
- New energy airport infrastructure: standards are required to harmonize practices and solutions relevant to new energy airport infrastructure and operations (e.g., H2 storage tanks, H2 liquefaction equipment, electrical charging stations…). Standards from several industries such as energy, transport, industrial, health and safety are expected to be adequate to address these needs. Currently, these standards do not consider aviation-specific considerations. As industry progresses in defining and refining these aviation-specific needs, updates of these cross-industry standards may be necessary.

AZEA WG4 expects the ICAO ADOP task to be the main source of data and information identifying gaps in standards relevant to Aerodrome Design and Operations. Coordination between AZEA and the ICAO ADOP task group has been established.

Concerning the New energy airport Infrastructure scope, AZEA WG4 has planned to launch a new task in collaboration with the WG2 (Electric/H2 supply chain), WG3 (Airports) and WG5 (Operations ConOPS) to identify gaps on Electric/H2 infrastructure standards. Currently, EUROCAE WG112-SG5 works on ground support for VTOL such as charging interfaces, fire-fighting, etc.

5. Conclusion

The journey towards integrating electric and hydrogen aircraft into mainstream aviation requires a foundation built on thorough preliminary work. While the potential for these technologies to revolutionize the industry is undeniable, it is essential to tread cautiously and methodically. This entails delving into various aspects, including but not limited to technological feasibility, safety considerations, regulatory frameworks, and environmental impacts. Instead, the primary focus should be on enhancing the understanding and knowledge base to comprehend the nuances and intricacies involved in harnessing electric and hydrogen power for aviation. The accurate identification of specific gaps in standards requires extensive research, testing, and analysis, examining the performance capabilities, reliability, and efficiency of electric and hydrogen propulsion systems under real-world conditions. Additionally, assessing the infrastructure requirements, such as charging and refueling stations, is crucial to ensure the practicality and scalability of these alternative propulsion technologies.

Standardization plays a crucial role in this development process, ensuring safety, interoperability, and efficiency across the industry. The WG-4's continuity is vital in maintaining momentum and addressing evolving challenges. There is a noticeable difference in the maturity of standardization work between hydrogen and hybrid-electric propulsion systems. Standards for hydrogen technologies are either non-existent, in the process of being formulated, or are less mature and require significant foundational work. In contrast, standards for hybrid-electric technologies are relatively advanced but still need further refinement and expansion. Additionally, the standardization ecosystem is inherently complex and involves multiple stakeholders, including manufacturers, regulatory authorities, and international bodies. Collaboration within this ecosystem is essential to develop comprehensive standards that cater to the diverse aspects of hybrid-electric and hydrogen aviation.

For hybrid-electric systems, the main gaps in standardization include performance metrics under various operational conditions, integration with existing aircraft systems, and establishing protocols for maintenance and safety. For hydrogen propulsion, the primary gaps lie in storage and distribution infrastructure, fuel cell technology integration, and ensuring the safe handling and refueling processes. Authorities' involvement is crucial in endorsing and enforcing these standards. The recognition of these standards as AMCs by regulatory authorities is essential, ensuring they are not merely guidelines but an acceptable criterion that must be met to comply with regulations. This regulatory backing is vital for widespread adoption and consistent implementation.

In summary, the journey towards integrating electric and hydrogen aircraft into mainstream aviation necessitates a robust standardization framework. This includes continuous efforts by WG-4, addressing the maturity differences between hydrogen and hybrid-electric systems, and managing the complexities of the standardization ecosystem. Identifying and bridging the main gaps in both technologies, coupled with active authorities' involvement, will pave the way for sustainable and innovative air transportation solutions.

ANNEX 1. Lifecycle Emissions for Electric and Hydrogen Aircraft

Aircraft with electric or hydrogen propulsion present zero CO_2 emissions in flight, hence the concept of "zero-emission aviation" in the name of the alliance. And while this constitutes a substantial benefit over kerosene-based aircraft from an environmental perspective, the environmental impact of electric and hydrogen aircraft is not zero. Looking at the (equivalent) lifecycle emissions of these aircraft, we can identify the following main non-in-flight-CO_2 contributions:

- LTO (landing/take-off cycle) and **in-flight non-CO_2 effects**, such as nitrous oxides (NO_X), soot, and water vapor emissions, and contrail and cirrus formation. These effects can be substantial; for example, the work of Lee et al. (2021) suggests the non-CO_2 effects of aviation on the climate are larger than the CO_2 effects.
- **Emissions created in the production of energy (hydrogen or electricity) for the aircraft**, i.e. well-to-tank emissions. If the electrical grid is not 100% renewable, then there are CO_2 emissions associated with the electrical energy needed to produce hydrogen or to directly charge the aircraft.
- **Emissions from the production of batteries:** in the case of battery-electric aircraft, batteries will have to replaced periodically when their state-of-health has degraded to a determined level. The production, recycling and/or disposal of batteries requires energy and also has a climate impact which must be included in the life-cycle analysis of such aircraft.
- **Emissions due to production of the airframe and components**: for commercial passenger aircraft, this climate-impact contribution is typically small compared to the in-flight and well-to-tank emissions. However, the reduced lifecycle emissions of hydrogen or electric aircraft, compared to kerosene aircraft, means that this contribution may become relatively more important.

Hydrogen and electric aircraft can have a substantially lower climate impact than kerosene or SAF-based aircraft (see e.g. the Clean Sky 2/FCH report on hydrogen-powered aviation). However, not all "sustainable" aircraft concepts are equally sustainable: if a power-to-liquid SAF, hydrogen, or even an electric aircraft obtains its energy (or energy carrier) from a "dirty" (e.g. coal-based) grid, the overall climate impact can be as bad or worse than a kerosene-based aircraft.

A detailed analysis of the emissions is not the purpose of this working group—that is addressed by other working groups in AZEA and outside of it—but it is clear that being able to quantify the lifecycle emissions of aircraft with new energy carriers is extremely important for a fair playing field for these new technologies. For this, standardized ways of assessing the lifecycle emissions are required. Being able to compare the climate impact of different aircraft (hydrogen, electric, kerosene, SAF,…) on an apples-to-apples basis is crucial for policy makers to be able to decide how "green" a technology, aircraft configuration, or energy supply is, and therefore how much support (e.g. financial or other incentives) it should therefore receive.

A. Current Standardization Landscape

Currently, EASA certification specifications related to emissions (CS-34, CS-CO2) refer to EU regulations 748/2012 (21.A.17 -21.A.21), which in turn refer to ICAO Annex 16, Volume II. Parts II and III of Annex 16, Volume II specify standards to determine engine emissions. Specifically, Part III states that the CO_2 emissions of the aircraft is quantified with the following metric:

$$CO_2 \text{ emissions evaluation metric value} = \frac{(1/SAR)_{AVG}}{RGF^{0.24}}$$

Where SAR is the specific air range, calculated as TAS/W_f (true air speed divided by total aeroplane fuel flow), i.e. a metric of how far the plane flies per unit mass of fuel. Moreover, RGF is a non-dimensional "reference geometric factor" based on the measure of fuselage size. Therefore, the CO_2 emissions metric gives an indication of the amount of fuel consumed per distance flow, and per "size" of payload that the aircraft can carry. Since it is applicable to kerosene aircraft, the fuel flow correlates almost directly with CO_2 emissions. This metric is therefore analogous to an "emissions per passenger-kilometer" metric. It is only applicable to a specific type of fuel, and does not account for non-CO_2 effects or any of the other lifecycle-emission contributions listed above. The ICAO documents specify standard ways of computing both SAR and RGF.

There are also ongoing efforts to define measures for non-CO_2 emissions of conventional fuel-based aircraft (see "State of play on aviation non-CO2 climate impact" document). However, there are no standards for calculating such contributions. This can partially be attributed to the fact that non-CO_2 effects such as contrail and cirrus formation are currently not fully understood yet.

B. Gap Analysis

The current emissions calculation standard of ICAO is not applicable to hydrogen or electric aircraft because it does not account for any emissions other than CO_2 emitted in flight (which is zero for hydrogen and purely battery-electric aircraft), and because the metric implicitly assumes a determined energy density and emissions index of kerosene.

Thus, standards are required on the following fronts:

- Metrics and measurement/test procedures to quantify impact of non-CO_2 emissions generated in flight such as water vapor, NOx, and contrails.
- Definitions of well-to-wake emissions and standards to measure it. Analogously to current fuel supplies, the energy supply (hydrogen, electricity,…) will have to be traceable such that the environmental footprint of the energy that is finally used on the aircraft is known.
- Definitions and measurement procedures to determine the environmental footprint of the batteries used on the aircraft.

To be able to compare the different technologies (hydrogen combustion, fuel cell, battery-electric, hybrid-electric, kerosene, SAF,…) on a like-for-like basis, a climate metric that is independent of the energy carrier must be defined. For example, analogously to current ICAO standards, a measure of the CO_2-*equivalent* emitted per passenger-kilometer traveled. In such a metric, the different contributions to the overall climate impact of the aircraft must be translated into an equivalent CO_2 contribution, i.e. how much CO_2 would be required to create the same climate impact. CO_2 can be taken as reference since its impact on global warming is relatively well understood, while this is not the case for e.g. emission of water vapor at altitude, or contrail/cirrus formation (see e.g. Lee et al., 2021).

Defining a standard metric and how to measure it is not straightforward, especially given the uncertainty that currently exists regarding the impact of the various contributions to the net global warming (often quantified as an "average temperature response" ATR over a determined time period, e.g. 100 years). However, if standards can be defined in a manner that is equal for all parties, even if it is e.g. conservative regarding the actual impact on global warming to account for uncertainties, then that will allow for a fair assessment of the different technologies.

ANNEX 2. Gap Analysis Hybrid-Electric Aircraft

Topics	Requirements	Sub-Topic	Gap in standardization	Reference	Standard	TC/WG	Gap in Standard
Terminology	MOC.EHPS.15		Existing standardized definition of EHPS in SC E-19. Fuel cell is not included in the scope of MOC.EHPS 15. Gap: "required by pilot or Flight Control System."	ARP8676	ARP Nomenclature and Definitions for Electrified Propulsion Aircraft	E-40	Missing definition on Hybrid.
				AIR8678	Architecture Examples for Electrified Propulsion Aircraft	E-40	Missing definition on Hybrid. Include all possible energy sources without specifying fuel cell (Generic Architectures)
				ER-025	List of standardization needs for Hybrid Electric Propulsion	WG-113	Provides incomplete EHPS definition
				ED-321	Guidance Material for Endurance Substantiation of Electric-Hybrid Propulsion	WG-113	Provides EHPS definition referencing SC E-19 MOC EHPS.15
EHPS Configuration	MOC.EHPS.20	Configuration Management	No standardized means to certify the engine as part of the aircraft.	ER-025	List of standardization needs for Hybrid Electric Propulsion	WG-113	Support the definition of the scope of the engine
				AIR8678	Architecture Examples for Electrified Propulsion Aircraft	E-40	Support the definition of the scope of the engine
Identification	MOC.EHPS.22		No need for new standards identified				
Instructions for Continued Airworthiness	MOC.EHPS.25		No need for new standards identified. Covered indirectly on standards based on components, reliability, maintainance.				
Instructions for Installation and Operation of the EHPS	MOC.EHPS.30		Missing the definition of IOM for EHPS (structure of IOM content). Need identified for installation materials applicable to EHPS.			E-40/WG-113	Identified as future activity by E-40 / WG-113 roadmap
Ratings and Operating Limitations	MOC.EHPS.40		Existing standard cover ratings and any further needs of the industry can be brought to the WGs to produce new revisions. This needs are driven by the novelty of distributed propulsion introduction.	ED-321	EHPS Guidance Material for Ratings Substantiation of Electric-Hybrid Propulsion	WG-113	Provides defintion of ratings.
				ARP 8689	Endurance test	E-40	Publication to be confirmed. Ratings coverage?
				IEC60034-1_ed13	Rotating electrical machines-Part 1 Rating and Performance	IEC	Referenced as guidance to shape ratings in ED-321. Level 2 standard.
Materials	MOC.EHPS.50	High Voltage new materials	Continue coordination between WGs to avoid duplication of efforts.	DP006/ARP 7380	Test guidelines for electrical insulation materials and components for a high voltage system	WG-116/AE-11	Refinement and adaptation to new materials being introduced
		Other materials	Mechanical parts, electronic parts, macnetic parts, et should be addressed (durability)	DP004	Guidance Material for Durability Substantiation of Electric-Hybrid Propulsion	WG-113	

Yellow color coding: EASA Priority 3 Level Approach.

Topics	Requirements	Sub-Topic	Gap in standardization	Reference	Standard	TC/WG	Gap in Standard
Safety Assessment	MOC.EHPS.80	LOPC	LOPC covered by the industry in SAE E40/36 and IEC, WG-116/AE-11 and AE-10. Need to further work on (1) Electric engine control system architecture and reliability (2) Energy Storage integration and its interactions with the EHPS and the Aircraft - EHPS FAA, ANAC, TACCA, EASA - CMT Task specific Team on EHPS	CMT-TST EHPS	Single Fault Tolerance and LOPC in Electric Engine Level 1 and Level 2.	CMT	Definition of LOPC for electric engine scoped to GA level 1 and level 2 single engine aircrafts. Strong industry need identified for single engine GA A/C level 3, dedicated to other A/C (multi-engine A/C, rotorcrafts, VTOL, distributed propulsion…). Published.
				AIR7130	Assessment of Electric Engine Failures Leading to LOPC	E-40	It covers full Electric Engine and it is applicable to CS-23 Level 1 and Level 2.
		Reliability		ARP5890	Reliability Database	AE-10, E-36, E-40, JC70	Traditional methodologies except Power electronics switches and HV capacitors. Focus on Reliability data and acceleration factor.
				ED-320	Aging mechanisms of electrical insulation materials in a high energy system	WG116/AE-11	Aging mechanism and test guideline for reliability evaluation of electrical insulation systems
				DP006	Test guidelines for electrical insulation materials and components for a high voltage system	WG116/AE-11	Aging mechanism and test guideline for reliability evaluation of electrical insulation systems
		Safety Assesment Guidelines	The state of listed standards remain valid. A more detailed gap analysis on safety guidelines will depend on case-by-case basis.	ED135/ ARP4761A	Safety Analysis Guidelines and Methods for conducting safety assessment process on civil airborne systems and equipment	WG-63/S-18	Generic to cover all types of aircraft
				ED79B/ ARP4754B	Guidelines for the development of civil aircraft and systems	WG-63/S-18	Generic to cover all types of aircraft
				DO-178C	Software considerations in Airborne Systems and Equipment certification	SC-205	Generic to cover all types of aircraft
				ASTM F3230-17	Standard Practise for Safety Asssessment of systems and equipment in small aircraft	F44	CS-23
				ARP8677	Safety Considerations for Electrified Propulsion Aircraft	E-40	Ongoing work targeting EHPS
EHPS Critical Parts	MOC.EHPS.90		No need for standards has been identified				
Fire Protection	MOC.EHPS.100		Need to develop Means of Compliance addresing Fire Protection for Hybrid Electric aircraft. Ongoing efforts for VTOL Fire protection standard in development. Priority 1 for EASA to produce MOC covering windmilling conditions after shortcut.	ASTM F3338-18, Chapter 5.5.1	Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft	F39.05	
				MOC.VTOL. 2330			
				DP003	Technical Standard on Rechargeable Lithium Batteries in eVTOL applications	SG1-WG-112	Not limited to VTOL. Any electric propulsion battery aimed to be applicable.
				DP001	Guidance on designated fire zone for VTOL	SG2-WG-112	Adressess VTOL Fire Zones
				DP005	Guidance for identification and mitigation of eMotor fire risks	SG2-WG-112	Not limited to VTOL. Any electric propulsion eEngine aimed to be applicable. Work coordinated with WG-113 to produce Fire qualification of electric engine.

Topics	Requirements	Sub-Topic	Gap in standardization	Reference	Standard	TC/WG	Gap in Standard
Static and Fatigue Loads	MOC.EHPS.200		No need identified to specific standard development. Fatigue Load is aircraft type independent.				
Strength	MOC.EHPS.210	Electrical stress analysis	No further gaps/needs are able to be identified at this stage.				
Vibration Survey	MOC.EHPS.230		Need to cover Electrical Rotor Insulation in future standardization activities.				
Rotating Parts Containment	MOC.EHPS.240/250	Electric engine containment test	CS-25 includes EHPS 240/250 requirement on Electric engine containment test. Need for the development of Rotating Parts Containment test standard Level 3 document. Detail method of demosntration of rotating parts containment is missing.	MOC EASA DRAFT		EASA	Missing containment demonstration guidance. Level 2 document
Continued Rotation	MOC.EHPS.260	Regeneration mode / windmilling	Safety compliance with MOC EHPS 260 demonstrated in the course of certification process. Important topic as architecture might differ between applications. WG-116 DP003 includes definition of electrical characteristics in regeneration mode introducing basic requirements.	DP003	Interface Characteristics and Power Quality of Aircraft High Voltage Propulsive Electrical Systems	WG-116	Includes the definition of electrical characteristics in regeneration mode.
		Engine short-circuit	Linked to fire protection topic				
		Mechanical stress	No need for standard at this point				
Rain Conditions	MOC.EHPS.270		Does not depend on the propulsion system. Applicability of current existing Regulation CS-E. No standards need identified.				
Icing and Snow Conditions	MOC.EHPS.280	Operations	Current standards applicable to operations.	ED-314	Compliance methodologies for VTOL certification in inadvertent icing operations	WG-112	Might be applicable to other aircraft architecture as the aim is to demonstrate that the aircraft is operative under icing conditions.
Bird, Hail Strike and Impact of Foreign Matter	MOC.EHPS.290	Electric Propulsor	Bird, Hail Strike addressed by VTOL. Need identified to develop standards covering MOC EHPS.290. An activity is being launched to address the topic at engine level.	F3338-21, WK70381	Standard Specification for Design of Electric Engines for General Aviation Aircraft	F39.05	Topic highly dependent on aircraft type
				F3338-18	Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft	F39.05	
					Industry has identified the need for addressing Electric engine ingestion, and is currently included in future work programme of E-40	E-40/WG-113	

Topics	Requirements	Sub-Topic	Gap in standardization	Reference	Standard	TC/WG	Gap in Standard
Fuel System	MOC.EHPS.300		Currently Fuel System requirement applicable only to hybrid systems (combustion or tubine engine) within EHPS. Overall need identified by the industry to extend the scope of E-19 to include Fuel Cell. The Hydrogen Management System would be need to addressed in the future. This will be independent of LH2 or GH2.				
Lubrication System	MOC.EHPS.310	Greased bearings	Need identified for the development of standards for lubricants applicable to gearbox lubrication, bearings lubrication and liquid cooling. Look at the link to fire protection depending on the quantity of liquid considered.				
Cooling System	MOC.EHPS.320		Need to further develop and harmonize a method for cooling systems demonstration for EHPS. Priority to consider flamability and electric conductivity of the lubrication system.				
Equipment	MOC.EHPS.330	Airbone Equipment	Applicability of current existing regulation to take into account failure modes when testing. No standards need identified.	ED-14 / DO-160	Environmental Conditions and Test Procedures for Airborne Equipment	WG-14	
				DP003	Interface Characteristics and Power Quality of Aircraft High Voltage Propulsive Electrical Systems	WG116	Power quality test definition (if not done as per EHPS 490)
Ignition system	MOC.EHPS.340						
EHPS Control System	MOC.EHPS.350	Airbone Equipment	Current standards are applicable to different aircraft architectures. No need for standards identified specific for EHPS. Need for MOC to be developed by EASA identified as Priority 1.	DO 160 G / ED-14G	Environmental Conditions and Test Procedures for Airborne Equipment	WG-14	Used for complex electronic hardware and software electronic qualification applicable to different aircraft types.
				DO 254 / ED-80	Design Assurance Guidance for Airborne Electronic Hardware	WG-46	
				DO 178 C / ED-12C Corrigendum 1	Software considerations and Airborne Systems and Equipment Certification	FAS	
				ARP4754A	Guidelines for the Development of Civil Aircraft and Systems	S-18	The guidelines in this document were developed in the context Part 25 and CS-25. It may be applicable to other regulations, such as Parts 23, 27, 29, 33, and 35 (CS-23, CS-27, CS-29, CS-E, CS-P).
				AIR7130	Assessment of Electric Engine Failures Leading to LOPC	E--40	
				DP004	Guidance for High Voltage Risk Mitigation at EWIS and Human Safety Level	WG116	Installation requirement for EWIS in an engine control system

Topics	Requirements	Sub-Topic	Gap in standardization	Reference	Standard	TC/WG	Gap in Standard
Time-Limited Dispatch	MOC.EHPS.355	Electronic Engine Control Systems		ARP5107_C	Guidelines for Time-Limited Dispatch Analysis for Electronic Engine Control Systems	E-36	Time Limited Dispatch (TLD) to the thrust control reliability of Full Authority Digital Engine Control (FADEC) systems.
Aircraft Instruments	MOC.EHPS.360			ED-309	Compliance methodologies for VTOL energy level information to the crew	WG-112 SG-6 Avionics	It addressess a general parts (failure modes for batteries for energy indication desing (i.e. desinging warnings for flight crew). Good part can be applicable for general use of EHPS, but partly focused on eVTOL.
Electrical Power Generation, Distribution and Wirings	MOC.EHPS.370	Personal Safety	Standards being developed focus currently on human safety. Current standard are limited in voltage level. Need to cover high voltage systems that take into consideration the gap: 1500VDC due to human risk of electrification. Another gap has been identified in the development of performance standard for HV. EWIS proportionality.	ED-290	Guidance on High Voltage Definition and Consideration for Personal Safety	WG112	Standards being developed focus currently on human safety and there its a gap in the development of performance standard for HV with regards to connectors, plugs, vehicle couplers, charging interfaces.
		Power Quality		ED-296	Guidance on Design Assurance for High Voltage Standards and Power Quality for VTOL Applications	WG112	Interfaces between equipments (voltage spike, ripples, back IMF) covering VTOL, but also applicable to other aircraft configurations. Good document for general electrical aviation
		Interface		DP003	Interface Characteristics and Power Quality of Aircraft High Voltage Propulsive Electrical Systems	WG116	The task objective is to build the electrical requirements for higher voltage electrical networks that will be used to specify, develop and verify electrical equipment and systems that may be used for electrical propulsion.
		EWIS and Human Safety Level		DP004	Guidance for High Voltage Risk Mitigation at EWIS and Human Safety Level	WG116	Limited in voltage level, high voltage systems might not be covered by WG-112/WG-116. Gap: 1500VDC due to human risk of electrification
Propulsion Battery	MOC.EHPS.380	Batteries	Lack requirements for energy reserves for small aircrafts. Gap between CS-23 and E-19, as not including propulsion battery.	DO311A	Minimum Operationale Performance Standards for Recharcheable Lithium Batteries and Battery Systems	SC-225	
				MOC EASA	MOC-3 SC-VTOL Issue 2		
				ED-xxx	Process Standard for crashworthiness test of battery systems for eVTOL applications	WG112	Crashworthiness specific requirement for PS, need for new means of compliance for CS-23.
				ED-289	Guidance on determination of accessible Energy in Battery Systems for eVTOL Applications	WG112	Specific to eVTOL. Lack requirements for energy reserves for small aircrafts. Gap between CS-23 and E-19, as not including propulsion battery.
				ED-XXX	Technical Standard on Rechargeable Lithium Batteries in eVTOL applications	WG112	
				ED-312	Guidance on Determining Failure Modes in Lithium-Ion Cells for eVTOL Applications	WG112	
				ED-xxx	Guidance on Common Cause Analysis of Lithium Ion Cells	WG112	
				ED-308	Guidance on VTOL Charging Infrastructure	WG112	

Topics	Requirements	Sub-Topic	Gap in standardization	Reference	Standard	TC/WG	Gap in Standard
General Conduct of Tests	MOC.EHPS.410		ED-321 provides guidance on endurance testing considering requirements in EHPS.410.	ED-321	Guidance Material for Endurance Substantiation of Electric-Hybrid Propulsion	WG-113	provides some guidance in the context of the endurance demonstration
Endurance Demonstration	MOC.EHPS.420	Endurance	Current standards need coordination and harmonization. Document updates might follow, although no further need to develop new standards in EHPS endurance demonstration. ED-321 reference as Acceptable MoC for EHPS 420.	ED-321	Guidance Material for Endurance Substantiation of Electric-Hybrid Propulsion	WG-113	
				ARP8689	Endurance Tests for Aircraft Electric Engine	E-40	
Durability Demonstration	MOC.EHPS.430	Durability	No further needs are identified at this stage as standards indicated are being drafted to address EHPS durability demonstration.	DP004	Guidance Material for Durability Substantiation of Electric-Hybrid Propulsion	WG-113	
				DP003	Interface Characteristics and Power Quality of Aircraft High Voltage Propulsive Electrical Systems	WG116	High voltage range used during durability (common mode voltage)
Calibration Assurance	MOC.EHPS.440		Addressed by ED-321.	ED-321	Guidance Material for Endurance Substantiation of Electric-Hybrid Propulsion	WG-113	provides some guidance in the context of the endurance demonstration
Teardown Inspection	MOC.EHPS.450		Addressed by ED-321.	ED-321	Guidance Material for Endurance Substantiation of Electric-Hybrid Propulsion	WG-113	provides some guidance in the context of the endurance demonstration
Operational Demonstration	MOC.EHPS.460		No standardization needs identified at this stage. Power reponse, reference to CS-E				
Rotor Locking Demonstration	MOC.EHPS.470		No standardization needs identified at this stage				
EHPS Specific Operation	MOC.EHPS.480		EHPS specific operation need standardization for specific rating on temperature and susbtatiation of the representativeness of the propeller				
System, Equipment and Component Tests	MOC.EHPS.490	Airbone Equipment		ED-14G/DO-160G	Environmental Conditions and test procedures for airborne equipment	WG-14	
				ARP5757A	Guidelines for Engine Component Tests	E-36	
				DP003 ED-xxx	Interface Characteristics and Power Quality of Aircraft High Voltage Propulsive Electrical Systems	WG-116	Power qualitity test definition (if not done as per EHPS 330)

ANNEX 3. List of Needs Hydrogen Aircraft

	Topic	Subtopic	Need	Applicability		Aviation Standardization		Comments
				GH2	LH2	Committee	Publications/ Activities	
Engines and Aircraft Systems & Components	On-Board Storage & Distribution	Tanks	Types of tanks (technologies & construction)	x	x	EUROCAE WG-80/ SAE AE-7F	DP005/AS7373 DP003/AS6679	
			Leak proofness: prevention (test) & protection	x	x	EUROCAE WG-80/ SAE AE-7F	DP005/AS7373 DP003/AS6679	
			Crashworthiness (design & test)	x	x			
			Tank fire & explosion (inerting, venting, etc.)	x	x	EUROCAE WG-80/ SAE AE-7F	DP005/AS7373 DP003/AS6679	
			Venting	x	x	EUROCAE WG-80/ SAE AE-7F	DP005/AS7373 DP003/AS6679	
			Sloshing		x			General comment: need to decide if/where the industry needs to cover supercritical conditions.
			Environmental tests (salt immersion, vibration, etc. DO160-type)	x	x			
			Structrural tests	x	x			
			Aging & durability (design considerations & tests)	x	x			
			Tank fuel quantity measurement	x	x			
			Methodology to measure & demonstrate minimum level of useable fuel	x	x			
			H2 contamination/filtering within the tank	x	x			
		Tank emptying/venting	Design and aircraft installation guidelines for a venting system (may be applicable to tanks, pipes, etc.)	x	x			
			Tank & H2 fuel system emptying, purging & inerting procedures (also maybe physical interfaces?)	x	x			
		Distribution system purging & inerting	Methodology, means and substances (inculding inerting fluids/gases)	x	x			
			Interfaces between purging/inerting system and fuel system	x	x			
		Foreign Object Debris	Detailed needs TBC	x	x			Most environmental qualification (DO-160-type) covered by equipment/component-level qual below. TBC if there are additional specific needs (insect or other)
		Electrical Bonding	Guidelines to control the build up of static electrical charges.	x	x			AIR1662B (SAE AE-5A) provides guidance on mitigation of electrostatic hazards for traditional fuels but does not cover H2. AIR5128A (SAE AE-5A) provides guidance on grounding/bonding, also does not cover H2 (TBC if there are specific new needs). Storage/distribution documents at WG-80/AE-7F cover ignition risks, TBC if they are

								sufficient to specifically covers electrostatic risks and appropriate mitigation.
		Fuel temperature conditioning (heat exchangers, etc.)	Thermal Modelling (Analysis)	x	x			
			Coolant Type/Specification	x	x			
		Pipes	Materials	x	x			
			Leak proofness: prevention (test) & protection	x	x			
		Sealings & connections	Materials	x	x			
			Leak proofness: prevention (test) & protection	x	x			
		Protection vs excessive pressure at fuel system level	Test	x	x			TBC if there is a need for a standard at this level or if component-level tests are enough (integration tests would then be application-specific).
	H2/LH2 Equipment & Components	Design rules & practices for electrical equipment & components located in H2 leakage zones		x	x			
		LH2 pumps	Failure modes, rates & effects + design considerations		x			
			Tests (performance, containment, etc.)		x			
		GH2 compressor	Failure modes, rates & effects + design considerations	x				
			Tests (performance, containment, etc.)	x				
		LH2 vaporiser	Failure modes, rates & effects + design considerations		x			
			Tests (performance)		x			
		Heat exchangers	Failure modes, rates & effects + design considerations	x	x			
			Tests (performance, structural, icing)	x	x			
		Valves	Failure modes, rates & effects + design considerations	x	x			
			Tests (performance, structural, icing)	x	x			
		Filters	Design considerations (performance, bypass)	x	x			
		H2 Fuel Flow measurement	Failure modes, rates & effects + design considerations (performance (accuracy, etc.), flow ranges etc.)	x	x			
			Tests (performance)	x	x			
		Equipment qualification & environmental tests	Fire & explosion resistance/proofness of components and equipment	x	x			
	H2 Combustion Engines	Architectures	Description of reference/example engine architectures (various types of hybridization, dual/multiple fuels, etc.)	x	x			
		H2 Gas Turbines						No clear technical need identified at full engine level yet, consider removing line and ensure the sum of all other lines is enough to cover all standardization needs.

		H2 Piston Engines						No clear technical need identified at full engine level yet, consider removing line and ensure the sum of all other lines is enough to cover all standardization needs.
		Engine H2 Fuel System Purging & Intertization	Design considerations & tests (including cranking and in-flight venting), including those affecting GSE	x	x			
		Control system	Engine control and control system components	x	x			Probably nothing to standardize for hydromech/electromech (FMU, etc.). TBD if updates to existing standards on engine controls are necessary.
			Single-fault tolerance to LOPC/LOTC	x	x			
			Time-limited dispatch (TLD)	x	x			
		Engine ingestion	Water, ice, birds, sand/dust, etc.	x	x			TBD if anything new is required vs traditional engines. Even if there is nothing new, existing standards should be expand their scope to H2.
		Endurance and durability	Endurance and durability demonstration	x	x			No standardized tests other than endurance/durability foreseen at this point. Ask EASA if they foresee other types of tests (ratings demonstration & other performance tests) to be addressed by standards in the future.
	Fuel Cells	Electrical Hazards	EMI/EMC	x				There may be nothing specific to FCs vs electric propulsion in general => likely covered by electc/hybrid propulsion matrix.
			HVDC Power Quality	x				There may be nothing specific to FCs vs electric propulsion in general => likely covered by electc/hybrid propulsion matrix.
			Electrical faults - isolation, bonding, etc	x				TBC if there is a need for guidance specific to FC systems or if guidance developed for electrical systems and components is enough.
			Ionization or contamination of cooling liquid.	x				TBC if ionization and contamination should be grouped. The risk is for the cooling liquid to become conductive and reduce the FC voltage and/or create leakage paths to the rest of the aircraft.
		Performance	Performance characterization & demonstration (including test)	x		EUROCAE WG-80/ SAE AE-7F	DP006/AS7141	Includes steady-state and transient performance, start-up/shut-down, etc.
			Fuel Cell conditioning (procedures & constraints at startup depending on previous exposure to low temperatures, etc.)	x				
		Environmental Tests	Loads (casing constraints)	x				TBD if there is a need for tests specific to fuel cells: could be warranted due to the construction of the fuel cell ("sandwitch" arrangement in the stack) for which combined cycle testing could be necessary.
			Vibration	x				
		Safety	Failure modes, rates & effects + design, manufacturing and maintenance considerations (driving safety, durability, etc.)	x		EUROCAE WG-80/ SAE AE-7F	DP006/AS7141	
		Aging and durability	Health monitoring: monitoring and detection of FC aging and	x		EUROCAE WG-80/ SAE AE-7F	DP006/AS7141	

			degradation to ensure sufficient performance (eg. sensors, warning system)					
			Endurance and durability tests (eg. delta V by hour, etc.)	x		EUROCAE WG-80/ SAE AE-7F	DP006/AS7141	Intent is to include critical parameter analysis identifying drivers for the endurance and durability tests (i.e. critical features of the fuel cell and the stressors that lead to their degradation).
		Fuel & air contamination	Fuel cell contamination, including air and fuel purity/contamination	x		EUROCAE WG-80/ SAE AE-7F	DP006/AS7141	
		Transport and storage		x				- Using nitrogen to create an inert base in the container/casing used in hydrogen transport. Safety-related criterion. - Fuel cells may vary the need for casing. Nitrogen may be recommended for FC, depending on the casing. => These risks may be covered by regulation/standards applicable to transportation of dangerous goods => TBC (to be assessed as part of the airport ops/infrastructure topics).
		Production acceptance tests (tests performed on every unit produced)		x				Minimum safety to be guaranteed. Safety tests may vary but include electrical insulation (be sure about insulation before connecting the fuel cell stack to the electrical network). It could be relevant to have a standard provide information about the types of tests that would be required to achieve these objectves. In the end, the test schedules themselves are likely to be application-specific.
		Cooling		x				There may be opportunities for standardization of the cooling liquid itself if there are solutions specific to FCs that are shared across the industry. - Compatibility of the coolant with the fuel cell plaques materials (List of the component compatible). -Standardize compatible types of cooling liquids.
		Modeling and modeling tools (power management prediction, performance, etc.)		x				Probably premature to identify precise objectives for a standard. Will be revisited iteratively as the industry matures.
	Materials	H2 tolerance of materials (including corrosion & embrittlement)	Design considerations	x	x			
			Tests	x	x			
		Tolerance of materials to LH2 and other cryogenic liquids/gases	Design considerations		x			
			Tests		x			
	Integration	Aircraft integration of electrical and H2 systems	EWIS rules for H2 aircraft	x	x			

	Leak & Fire/Explosion Detection & Accommodation	H2 sensors (detecting the presence of gaseous H2 in a given location)	Sensor performance (accuracy, sensitivy, range): performance levels and methodologies to characterize it, including calibration	x				Need to check if any such standards exist from other industries.
			Protection of the sensor vs external threats (flameproof, pressurised enclosures, UV light protection, etc)	x				TBC if it is relevant to standardize this. Need to check if any such standards exist from other industries.
		Leak accommodation (ventilation, etc.)	Guidance on means and methods to accommodate leaks (ventilation, flow rates, crew alerts, etc.)	x	x			
		Zoning (Fire, explosion, asphyxiation & cryogenic risks)	Definitions and design guidelines for fire zones (expansion of definition of current fire zones and/or creation of new H2-specific fire zones)	x	x			
			Definitions and design guidelines for flammable fluid/gas zones (expansion of definition of current fire zones and/or creation of new H2-specific flammable fluid leakage zones)	x	x			
			Definitions and design guidelines for cryogenic zones	x	x			
		Fire & explosion prevention & protection	Characterization of H2 flame	x				
			Fire testing	x				
			H2 leakage rates	x	x			
		H2 releases (assessment and control of consequences of H2 release, etc.)		x	x			
		Firewalls	Identification of possible functions for a firewall	x	x			
			Maximum leak rate, temperature, etc.	x	x			
	Crashworthiness	Flare off/emptying of storage tanks after incident		x	x			
		Crash survivability	Design considerations	x	x			
			Test procedures (tank drop tests, etc.)	x	x			
Fuels	Fuel characteristics	LH2/GH2	Fuel purity/contamination	x	x	ASTM D03	WK85474	
		Ammonia, methanol & LNG as fuels for aviation						No short-term needs identified.
		Alternative carriers (LOHC/LIHC, metalhybride)						No short-term needs identified.
Ground Operations	Refueling	Fuel quality assurance at refueling point (including testing)	Test procedure	x	x			
			Testing means	x	x			
		Fuel quantity measurement/metering at refueling point	Minimum measurement performance	x	x			
			Physical interface standard	x	x			

		Interface between refueling system and aircraft	Communication & protocols between A/C and refueling system	x	x			
		Refueling system materials & hoses		x	x			
		Refueling system/vehicle performance		x	x			
		Refueling procedure		x	x			
	Maintenance	Line maintenance	Safety and operability considerations for maintenance.	x	x			General need: making sure that procedures and practices are in place to ensure the safety of human intervention in potentially explosive atmospheres. TBC if this can be standardized.
		Shop maintenance						
	Aircraft parking/storage	Aircraft dormancy (overnight parking)	Aircraft preparation for dormancy	x	x			
			Aircraft monitoring & protection	x	x			
			Aircraft preparation for operations	x	x			
		Aircraft dormancy (> 1 day)	Aircraft preparation for dormancy	x	x			
			Aircraft monitoring & protection	x	x			
			Aircraft preparation for operations	x	x			
	Emergency Response	Emergency first response		x	x			
		Flaring & cryogenic risks		x	x			
Markings	Markings							TBC if this can be included in another category. This is a general need spanning everything from aircraft down to component level.
Flight Operations		Flight & cabin crew training						Maybe start from EASA Air OPS (Part 91...)
		Pre-flight inspections						
Airport Infrastructure	Airport H2 Production	Electrolysis						
		Gasification						
		Purification & quality control						
	Airport H2 Storage	Liquefaction						
		Gaseous or liquid storage						
		Alternative carriers (LOHC/LIHC, metalhybride)						
	Airport H2 Distribution	Hydrant system						
		Transfer tanks						
Sustainability, Origin & Atmospheric Emissions	Definition of wheel-to-well carbon footprint measurement, GHG emissions saving and KPI			x	x			
	Guarantee of origin of delivered gas			x	x			
	H2 release	Emergency & nominal (expected leaks, venting) release		x	x			

	H2 Combustion Emissions	NOx and possibly other types of emissions	Measurement methodology to demonstrate compliance with possible future ICAO/AA rules	x	x			TBC if there is a new need vs legacy engines
	Contrails			x	x			
Training								

ACITURRI AERnnova ASD AIRBUS

Air Liquide AURA AERO beyond AERO BLUE SPIRIT AERO

CENA Hessen cen CENELEC CLEAN AVIATION Collins Aerospace

Cranfield Aerospace Solutions ELSA INDUSTRY EUROCAE EUROCONTROL

CTA Avio Aero A GE Aviation Business GAMA General Aviation Manufacturers Association H3 Dynamics

Heart Aerospace ITP Aero kopter LEONARDO LILIUM

NACO a company of Royal HaskoningDHV NRG 2fly ONERA THE FRENCH AEROSPACE LAB PANTA HOLDINGS

PRATT & WHITNEY DEPENDABLE ENGINES nlr SAFRAN dgac STAC

Universal Hydrogen VÆRIDION WIDERØE ZERO ZEROAVIA