

ENTRY INTO SERVICE REQUIRES CERTIFICATION FOR NOVEL TECHNOLOGY

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Abstract

Novel aerospace product technologies, such as electrified aircraft propulsion (EAP), are seeking Entry Into Service to deliver unique operational capabilities. While the technology development for these EAP-capable vehicles is progressing well, the path to bringing them into service is daunting. Traditional aircraft propulsion is steeped in conventional turbine and reciprocating engines. The impediment to many of these novel vehicles entering service is a lack of civil aviation safety regulations, standards, and compliance methodologies to enable the certification of these novel vehicle technologies, thereby ensuring they meet the overall safety level of the existing aircraft fleet.

This paper describes the differences between traditional technology development that builds on decades of technology risk reduction that informs both certification and standards, differs from the current EAP development practice where innovative developers are using standards development organizations to build industry-consensus standards to be used as proposed means of compliance with regulators. And in the process to safely accelerate the novel vehicles' entry into service.

The opportunity that the National Aeronautics and Space Administration (NASA) provided with its early flight demonstration vehicles provided a way to assess and prioritize the gaps in the current civil aviation regulations that EAP posed. NASA's Electrified Powertrain Flight Demonstration (EPFD) project innovated a unique opportunity to engage directly with industry partners and advance both the technology development with the highest priority standards necessary to enable hybrid-electric, transport category airplane entry into service a decade earlier are described.

Finally, the paper describes four key areas for future work: (1) Apply standards maturity level tracking to technology development projects. (2) Integrate regulations and standards, into cross-cutting technology infusion into technology development. (3) Integrate ground- and flight-test data into the development of standards that can be used for certification. (4) Use digital engineering tools to accelerate the investigation of regulatory gap assessment.

Keywords: Standards, Regulations, Certification, Novel Vehicles, Electric Aircraft Propulsion

1. Introduction

Novel aerospace product technologies, such as electrified aircraft propulsion (EAP), are seeking Entry Into Service to deliver unique operational capabilities. While the technology development for these EAP-capable vehicles is progressing well, the path to bringing them into service is daunting. Traditional aircraft propulsion is steeped in conventional turbine and reciprocating engines. The impediment to many of these novel vehicles entering service is a lack of civil aviation safety regulations, standards, and compliance methodologies to enable the certification of these novel vehicle technologies, thereby ensuring they meet the overall safety level of the existing aircraft fleet. Each civil aviation regulatory authority has policies and procedures to address the lack of regulations for novel technologies, called “Special Conditions.” In the United States, the Federal Aviation Administration (FAA) issues special conditions when it finds that the airworthiness regulations for an aircraft, aircraft engine, or propeller design do not contain adequate or appropriate safety standards because of a novel or unusual design feature. Another method that the FAA has used to address regulatory gaps is via the issue paper process for “special class airworthiness criteria.” This method has the regulatory requirements defined in a certification basis issue paper. The proposed custom airworthiness criteria are usually performance-based. To address the generality of performance-based airworthiness criteria, compliance would also be accepted through the issue paper process. In the European Union, the European Union Aviation Safety Agency (EASA) issues Special Conditions based on the EASA Management Board's December 2007 decision, which establishes certification procedures for novel technology to ensure an equivalent level of safety to that required by regulations for established technology. However, the means by which a novel technology is evaluated remain to be developed. This knowledge gap is one that the technology innovator is uniquely skilled to address by proposing means of compliance to ensure the safety of their novel vehicles. The technology innovator, together with the relevant regulatory authority’s certification policy specialists, must develop these new certification frameworks. This paper describes the landscape of successful novel technology companies that are moving forward, as well as lessons from those that did not pay attention to certification early enough. This paper will compare the special conditions and issue papers from two regulatory authorities and show where they harmonized and where differences still require technical analysis. This paper reveals the importance of using Standards Development Organizations as a crucible for developing the means by which technology can be certified, in a unique form essential to introducing novel vehicles into service.

2. Technology Development

Traditionally, technology development results from an innovative idea that begins as a concept and with sufficient identification and reduction of technology risks, results in the genesis of a product that can be produced. This process has been articulated in a number of approaches, including the Technology Readiness Level [1] (TRL) defined by the U.S. National Aeronautics and Space Administration (NASA) in the mid 1990s to articulate technology progress supporting Science Missions. Other organizations within NASA, including those supporting Aeronautics research adopted the TRL scale. TRL became a means by which to characterize progress of moving a concept to reality.

2.1 Traditional Technology Development

For much of the 1990s and into the 2010s, novel vehicle technology development centered around turbine- and reciprocating engine propulsion. The Integrated High Performance Turbine Engine Technology [2] (IHPTET) project from the US Air Force was a collaboration of turbine engine manufacturers, and gathered across the US research organizations, including NASA and the U.S. Federal Aviation Administration (FAA) to advance the state of the art of turbine engine technology. The Advanced General Aviation Transport Experiment [3] (AGATE) project from the US NASA was a collaboration of general aviation manufacturers, and also gathered across the US research organizations, including the FAA, to accelerate the development of innovative safety technologies for normal category airplanes. The Fly-By-Light/Powered-By-Wire [4] (FBL-PBW) project from NASA

focused developing technology that was less affected by electromagnetic interference and less reliance on mechanical connections to flight controls, and the NASA project complemented the USAF More Electric Aircraft [5] (MEA) project.

The advanced concepts from these projects, as well as others focused on the robust knowledge and history of current aircraft engine technology, and standard flight controls and actuation. For IHPTET and AGATE, the advances in the state of the art were well documented, and complemented the current knowledge and operating experiences.

For these cases, the results of technology development easily fit into the current certification knowledge base. For example, the work in digital engine controls in the late 1980s and 1990s resulted in a solid foundation for their certification. Advances in turbine engine technology laid the foundation for novel concepts, such as geared turbofan and its entry into service. Advances from AGATE for the reciprocating engine community enabled new, more efficient engines.

For over 30 years, technology development was used as clear indicator of the ability for a novel technology to enter into service, since certification of the novel technology would only require tailoring of existing regulations. The existing regulations for aircraft engines, which had specific references to reciprocating and turbine engines, would be tailored to accommodate the improved turbine and reciprocating engine technologies. Even novel vehicles using composite structures and digital flight controls could be addressed by tailoring existing language in the regulations for normal category and transport category airplanes and rotorcraft.

2.2 Enter Electric Aircraft Propulsion

Advanced vehicle concepts that rely on electric aircraft propulsion (EAP), however, require significant change to existing regulations since there are no references whatsoever for EAP. This would become a significant stumbling block for advanced EAP vehicles. Tracking only the maturation of technology using Technology Readiness Level (TRL) without understanding how to assess progress to develop certification means of compliance would result in a serial technology development followed by a certification development project. It could result in an additional decade to enter the novel concept into service.

A new approach that incorporated the complementary development of certification means of compliance along with the technology development was required.

3. Aircraft Electrification

3.1 NASA's Interest in Aircraft Electrification

In 2005, as part of the NASA Vehicle Systems Program, the Personal Air Vehicle project considered the development of fully remote, electrically powered aircraft. The vehicle concept was called Puffin [6] and was developed in 2010. *"The Puffin has significantly influenced the development of personal air mobility and electronic aviation. By being the first (scale) eVTOL aircraft to take flight, the Puffin demonstrated the feasibility of electric propulsion in vertical flight, paving the way for subsequent advancements in the eVTOL industry."* [6]

NASA's interest in electrified aircraft was supported through its Convergent Aeronautics Solutions (CAS) project. One of the first competitions was awarded to a Slovenian company, Pipistrel. The company took its lessons and eventually built two electrically powered conventional take-off and landing (CTOL) aircraft as pilot trainers. In 2020, the Vellis Electro was certified by the European Union Aviation Safety Agency (EASA) as a Light Sport Aircraft.

The next NASA investigation of EAP began by leveraging NASA's Leading Edge Asynchronous Propulsion Technology (LEAPTech) effort, which was funded under a NASA Aeronautics Research Mission Directorate (ARMD) Team Seedling award. LEAPTech focused on a ground test of the low-speed aerodynamic qualities of a wing designed for a uniquely novel vehicle concept of Distributed Electric Propulsion (DEP) to enable a more efficient cruise design. This led to a new subproject within NASA's Convergent Aeronautical Solutions (CAS) project of the Transformational Aeronautics Concepts Program (TACP) with the goal of completing the LEAPTech ground test and advancing the DEP concept into a flight vehicle. This activity was known as the Scalable Convergent Electric Propulsion Technology and Operations Research (SCEPTOR) effort within CAS, which included flight of vehicles using a spiral development process in what were known as Mods I through III. As the scope of the effort grew, the activity transitioned to become a subproject of the Flight Demonstrations and Capabilities (FDC) Project within the Integrated Aeronautics Systems Program (IASP) and became known as the X-57 flight research vehicle [7]. Mod IV, which integrated all of the DEP concepts into a flight vehicle, was added to the FDC X-57 subproject in 2017. An overview of the planned test vehicles associated with each of these activities or subprojects is shown in Figure 1, and a timeline of the X-57 subproject is shown in Figure 2.

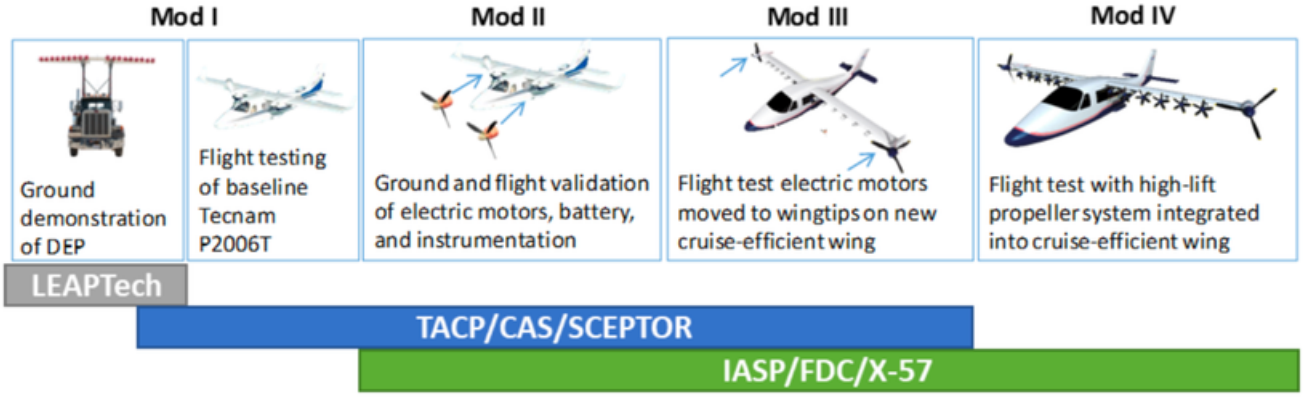


Figure 1 – Test vehicle scope for the X-57 and precursor activities.

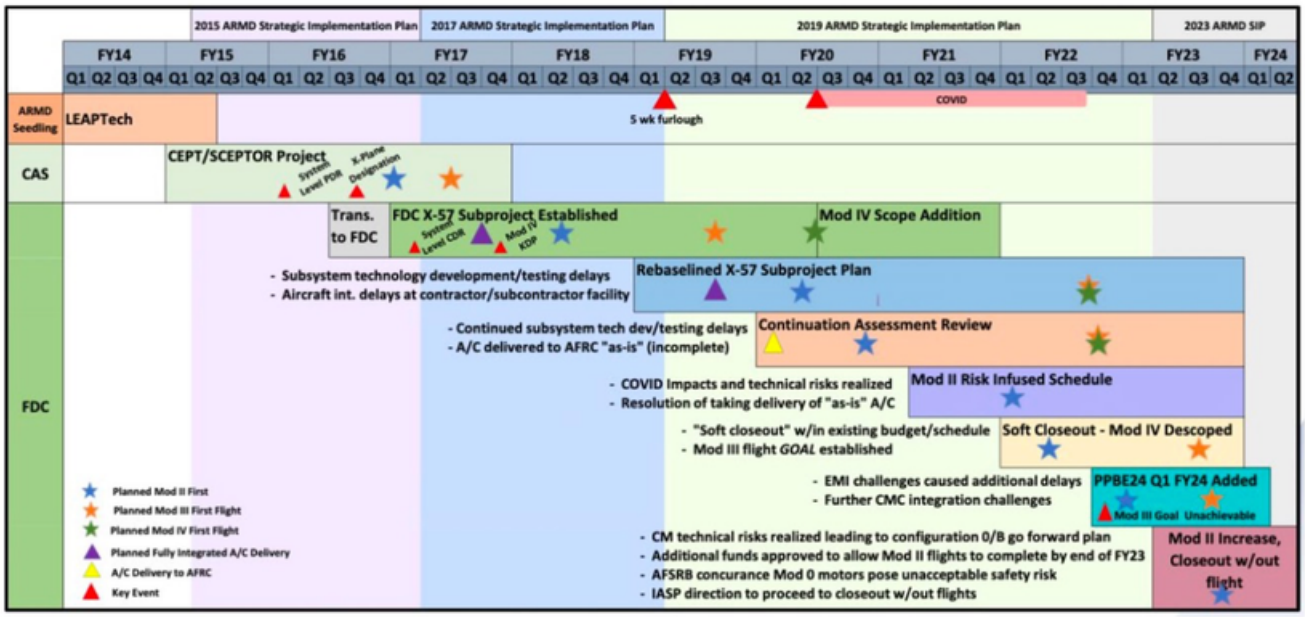


Figure 2 – X-57 timeline from LEAPTech to close-out.

The X-57 subproject scope evolved throughout the lifecycle due to technical challenges, resource limitations, and changing stakeholder and industry needs. Throughout the effort, the team worked diligently to advance the state of knowledge and technology of electric aircraft subsystems and DEP. These efforts provided invaluable information, which aided in the development of industry standards.

A formal Lessons Learned report was developed in 2023 for the X-57 project, which thoroughly identified issues of the technology development. One of the innovative aspects of the X-57 project was the development of a regulatory gap analysis of the novel technologies. In February 2023, NASA published the "X-57 Maxwell Airworthiness Validation Plan," [8] (AVP) which simulates a Certification Plan by assessing the variety of novel technologies in the X-57 against 14 CFR Part 23, Normal Category Airplanes, Part 33, Aircraft Engines, and Part 35, Propellers, along with the associated standards for those regulations. HS Advanced Concepts LLC was supported by Designated Engineering Representatives (DER) and other subject matter experts in the development of the Airworthiness Validation Report. This was the first published report examining the certification challenges with DEP and touched on a number of related challenges with EAP in general. It was also the first use of the Special Condition that the FAA had published for Electric Engines [9]. While the AVP was the first published regulatory gap analysis for a novel EAP vehicle, its engagement into the X-57 project was too late to change the technology development, the airworthiness process, and the eventual flight research effort, due to its late incorporation. Typically, a regulatory gap assessment is done well before a preliminary design review, and for NASA projects this would ideally occur during project formulation.

While the engagement into the X-57 was late, the regulatory gap analysis process was robust, and could be applied to other novel vehicle efforts. NASA ARMD adopted the regulatory gap analysis process for its next project which was in pre-formulation. That project was the Electrified Powertrain Flight Demonstration (EPFD) project. The EPFD was intended to demonstrate hybrid-electric, integrated MW-class powertrain systems on single-aisle and regional aircraft. This would be a very tall challenge, as the rest of the industry was focused on normal category airplanes and powered lift aircraft, this would be the first attempt to fly a transport category airplane under 14 CFR Part 25 regulations. Unlike Part 23 normal category airplane regulations, which under Amendment 64 were performance-based rules, Part 25 airplanes were proscriptive rules, meaning that all of the means of compliance are define a priori, and the challenge of developing certification means of compliance was significant. Two key elements were that the EPFD project would establish a regulatory and standards project element, and that the EPFD project would seek the insights and expertise of industry partners to both advance their technology development, and that the industry partners would propose their approach to close the regulatory gaps.

Meanwhile, the industry entrepreneurs were advancing the state of the art in EAP with eVTOL vehicles [10]. Concepts for urban air mobility to leverage aircraft electrification promised many innovative concepts and large investment of entrepreneurs who saw an opportunity to move into a completely new air mobility service. The race was on!

3.2 Entrepreneurial Innovation

The history of EAP certification projects is a mix of early adopters based on Part 23/CS-23 (under 12,500-pound aircraft), evolving to the new Powered Lift under Part 21/EHPS-19, and Part 25/CS-25, which is the focus of EPFD. There are also cases where early adopters neglected the development of MOCs for their vehicles in favor of developing demonstration flight vehicles. Figure 3 shows this in context.

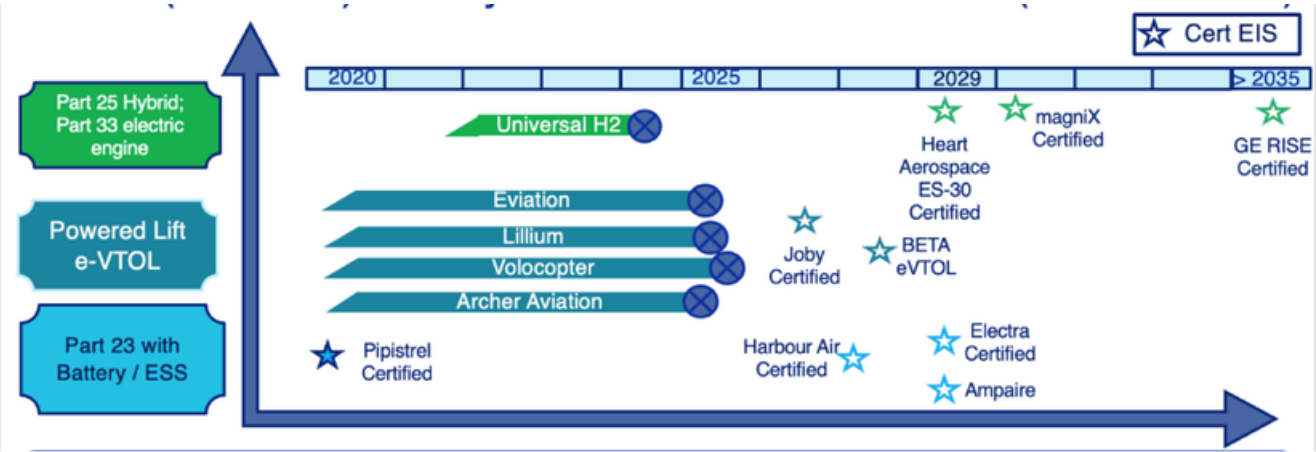


Figure 3 – Industry electrified aircraft propulsion certification efforts in the public domain.

For electric engines, covering the significant gaps in 14 CFR Part 33, the FAA Policy Certification specialists participate in the ASTM F39, F44, SAE E-40, and AE-10 committees and working groups. They are interested in developing standards to fill the technology barriers in the magniX Special Condition for Part 33 and the aircraft engine sections (in subpart H) of the aircraft special conditions for Joby and Archer. There are significant gaps in the knowledge of the special conditions, and their interest is keen. Fortunately, the Subpart H sections of the two aircraft special conditions are based on the magniX special condition.

4. Identifying and Prioritizing Gaps in the Regulations for EAP

4.1 The NASA-Industry Partner Approach to Identify Gaps in Regulations for EAP

Within EPFD, the Regulations and Standards Development (R&SD) team was formed to provide focus and leadership on behalf of the Project to assess and identify the highest priority certification gaps that will need to be addressed to truly enable electric flight. The R&SD team has worked closely with the Federal Aviation Administration (FAA) and other Standards Development Organizations (SDOs) to explain the approach the Project is using to assess these gaps, and it has solicited feedback from these organizations on our principal findings. The R&SD team understood early on that a close working relationship with the standards organizations was key to making expedited progress.

The EPFD R&SD team recognized a need to gather what had been isolated involvement by NASA Subject Matter Experts (SMEs) working individually on each of their own respective SDOs. By gathering these individuals together within NASA, into a Regulations and Standards Working Group (RASWG), it allowed for cross pollination of ideas and perspectives from other related SDO committees, as well as outreach to address barriers encountered in crafting the proper standards language that may be needed. The RASWG, meant as a government-only collaborations group, continued to grow in membership, inviting members from within related NASA Projects to join in the collaboration. Invitations have also been extended to related agencies (e.g., FAA and ARPA). This growing community of collaboration ensured wider discussions of the barriers to certification and viable approaches for overcoming those barriers. To continue to expose RASWG members to the latest development and challenges, industry members were invited periodically to present and share their respective challenges to achieving their goals for electric flight. While the project-specific certification plans are being worked individually between the FAA and each industry applicant for a certificate, most of the standards and technical discussions have taken place in the Standards Development Organizations (SDO) such as the ASTM [11] and SAE [12], with their focus on standards for means of compliance for aircraft and engine type certification activities.

The EPFD R&SD team established rigorous analyses to identify gaps in the current regulations that impede the entry into service of novel EAPs. These analytical approaches were shared with the

industry through SDOs. The EPFD R&SD team innovated the gap analyses using model-based systems analyses to better inform the SDOs needing development. They also engaged with the FAA and other regulatory authorities worldwide to establish a certification policy enabling EAP.

The approach taken by the Regulations and Standards Development to address novel single-aisle, integrated MW-class powertrain system technology was three-pronged, as illustrated in Figure 4.

The first step is assessing the existing civil aviation regulations for airplanes [13], engines [14], and propellers [15]. Although flight and air traffic operations are important factors, the priority for the initial assessment is the airworthiness standards for aircraft certification.

The second step involved assessing the integrated single-aisle, MW-class powertrain, system technologies. This was accomplished by conducting a generic regulatory gap analysis of both turboprop and turbofan vehicles and examining the technologies against the regulations. This was done while assessing each paragraph of the regulation as to whether it was suitable (unchanged), required a modest adjustment in detail (tailoring), whether it needed to be revised, or whether the paragraph was inapplicable. The resulting paragraph-level detailed assessment was then synthesized to find the highest ranking and priority to address. This level of evaluation provided insight for the EPFD R&SD team to assess the industry partners' product-specific regulatory gap analysis.

Finally, the EPFD R&SD process allowed each industry partner to conduct their technology assessment and product-specific regulatory gap analysis without prejudice to the NASA EPFD internal generic gap analysis. This provided a unique opportunity for NASA to learn the industry partners' methodology, key concerns, and priorities. It also assured that the industry partner could identify its draft gap analysis at PDR for discussion with the NASA EPFD R&SD team. This was then used as its baseline gap analysis at Critical Design Review (CDR), with updates through the remainder of the project. The key outcome is that the industry partner became the chief advocate to develop standards necessary to develop means of compliance at an early stage with their regulatory authority in the standards development environment.

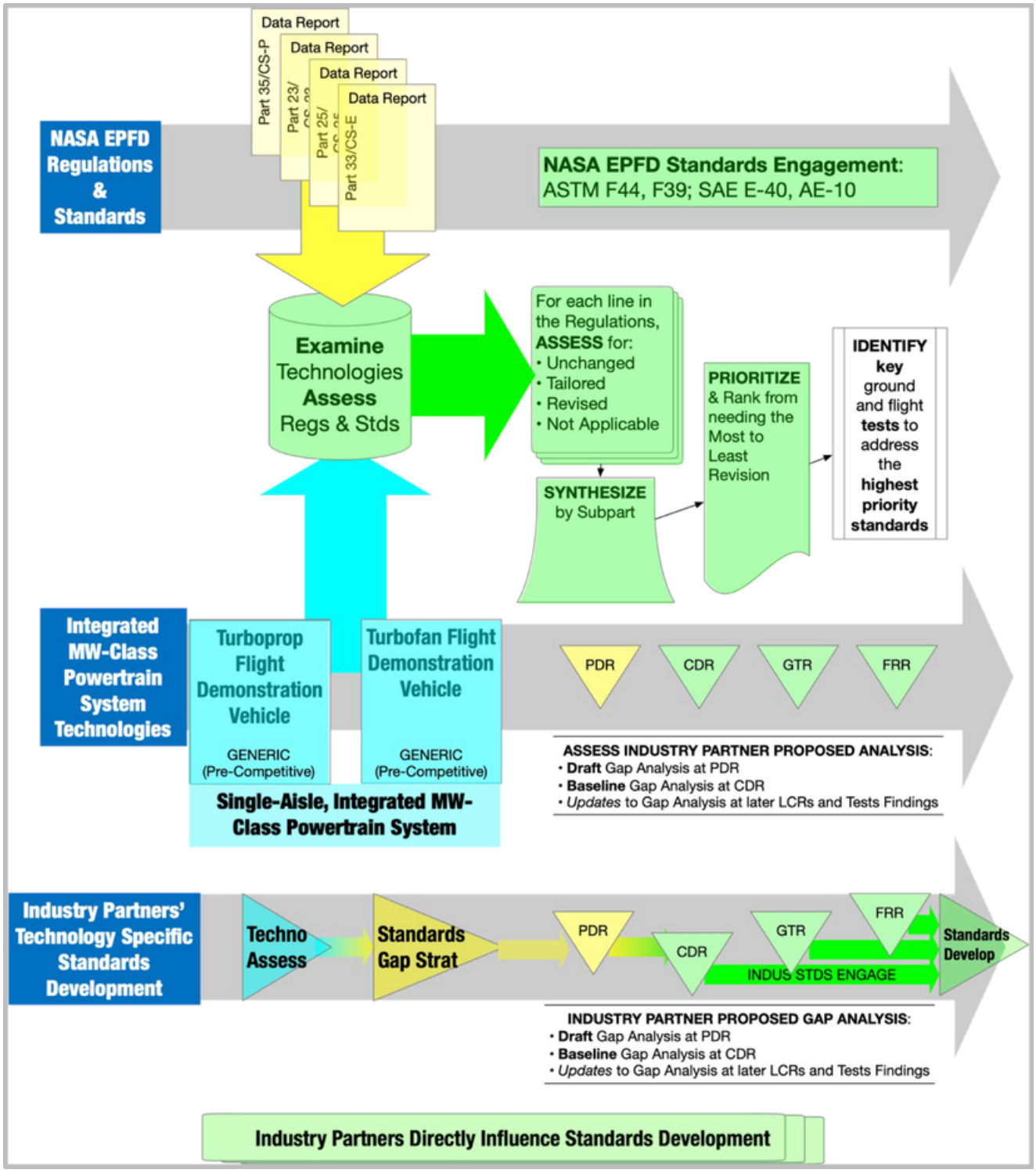


Figure 4 – Three-pronged approach to regulations and standards development with industry partners.

Each aircraft and electric engine manufacturer innovates their technology and coordinates with the FAA in the US and with the European Union Aviation Safety Agency (EASA) in Europe for their civil aviation certificates. Therefore, the FAA continually adjusts its approach to the Regulatory Procedures Act as the new certification projects are brought to them from applicants in the industry. This also precludes NASA from having a special relationship with the FAA as two US Government entities as neither solely exchanges technical information. It is the FAA, with the industry working with NASA, that the FAA can see the merit of a technology approach. This means the standards community is the premiere venue for NASA to work with the FAA.

While the project-specific certification plans are worked individually between the FAA and each industry applicant for a certificate, most of the standards and technical discussions have taken place in the SDOs, such as the ASTM and SAE, with their focus on standards for means of compliance for aircraft and engine type certification activities. [16]

Performance-based rulemaking (PBR), in the form of special conditions, has changed the role of standards work. Originally, standards collected industry (and government) data from existing products and projects to allow harmonization that improved safety or economics. In the current environment of electrified aircraft propulsion, with various special conditions for electric aircraft propulsion systems, standards work is now occurring before initial product introductions to support innovation, not harmonization. Figure 5 [17] illustrates this new approach to standards development in this PBR environment and the importance of data-informed dialog with the regulatory authorities by developing data-driven standards to comply with these PBRs.

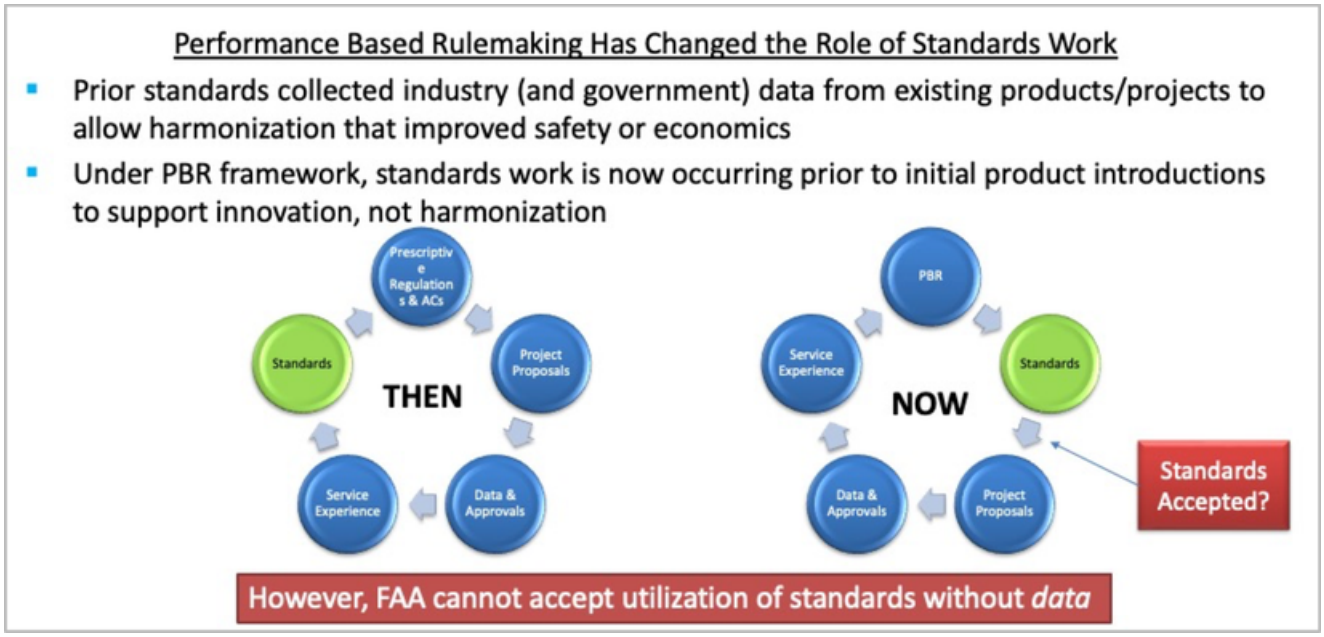


Figure 5 – The importance of data for today's standards (©2023, magniX).

As EAP, in its varieties, enters into service, a close working relationship between EPFD, R&SD, and the FAA, through the SDOs, has been critical in developing standards to fill regulatory gaps.

4.2 Results of the NASA Generic Hybrid EAP Gap Analysis

The EPFD R&SD team developed the generic regulatory gap analysis [18], in 2020 to describe an acceptable methodology expected of its industry partners. The generic gap analysis did not specify an architecture, as that would be provided by the eventual industry partners. The generic regulatory gap analysis examined all the elements in 14 CFR: Parts 23, Normal Category Airplanes, 25, Transport Category Airplanes; 33, Aircraft Engines; and 35, Propellers. The analysis was to find gaps in the current US FAA regulations based on generic hybrid electric engine technology and then to prioritize those gaps by the general headings of the subparts to the regulations. and archived to a place on the NASA EPFD Box repository.

Figures 6 through 10 show the summary by Subpart of each of the four regulations identified above. In each case the assessment identified whether the regulatory language was unchanged, required tailoring (such as minor changes in language to fit the generic hybrid-electric configuration), whether it required complete revision, or whether the language was not applicable. Each subpart was assessed by how much of the subpart had the highest number of tailored or revised language. A table summarizing the four figures follows.

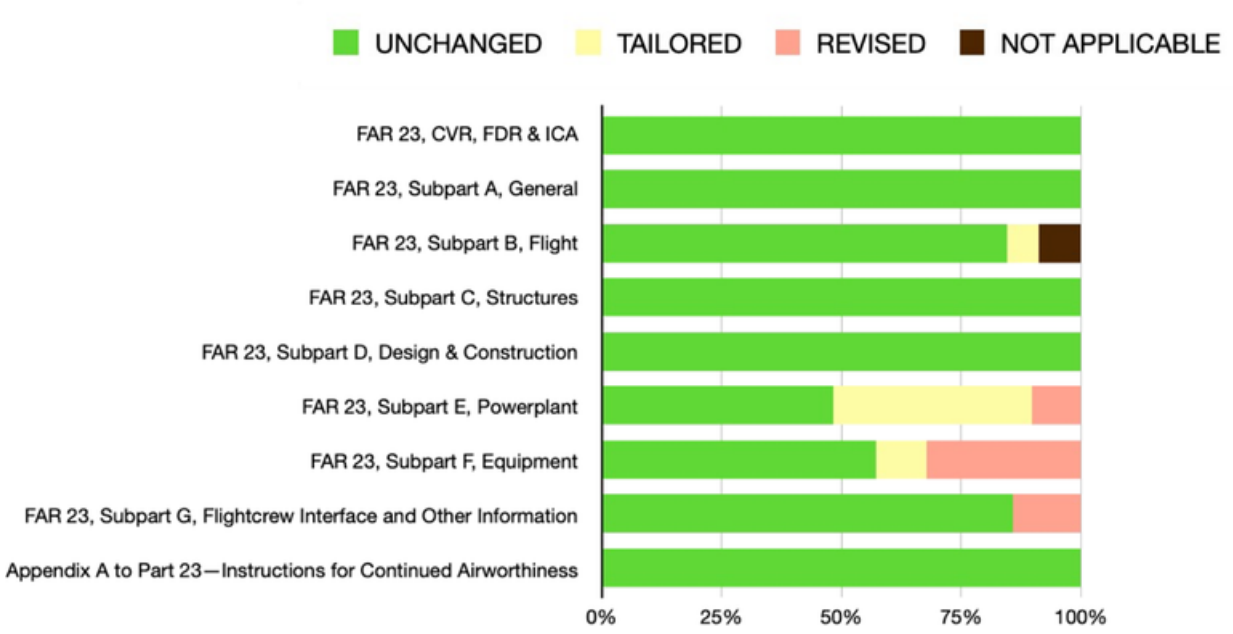


Figure 6 – Generic gap analysis of normal category airplanes.

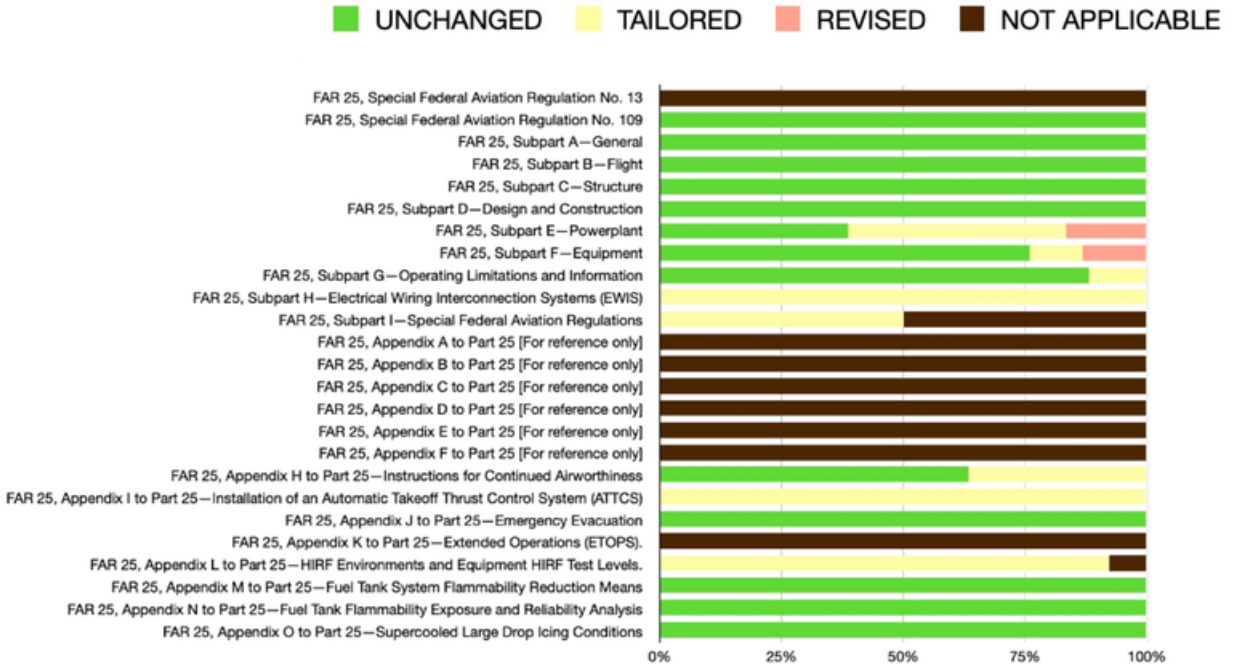


Figure 7 – Generic gap analysis of transport category airplanes.

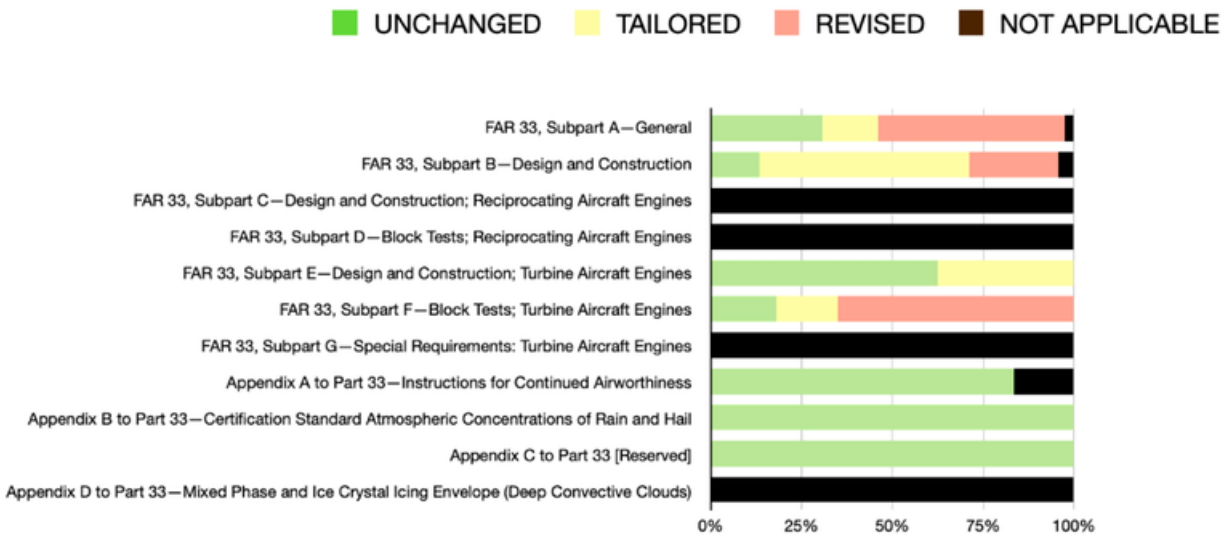


Figure 8 – Generic gap analysis of aircraft engines, hybrid-electric turboprop.

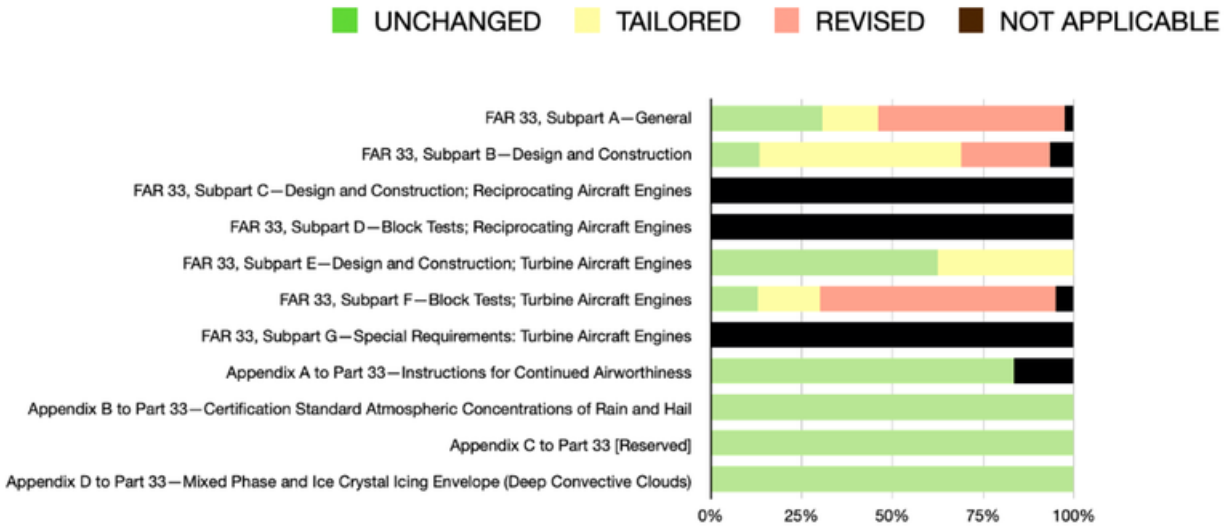


Figure 9 – Generic gap analysis of aircraft engines, hybrid-electric turbofan.

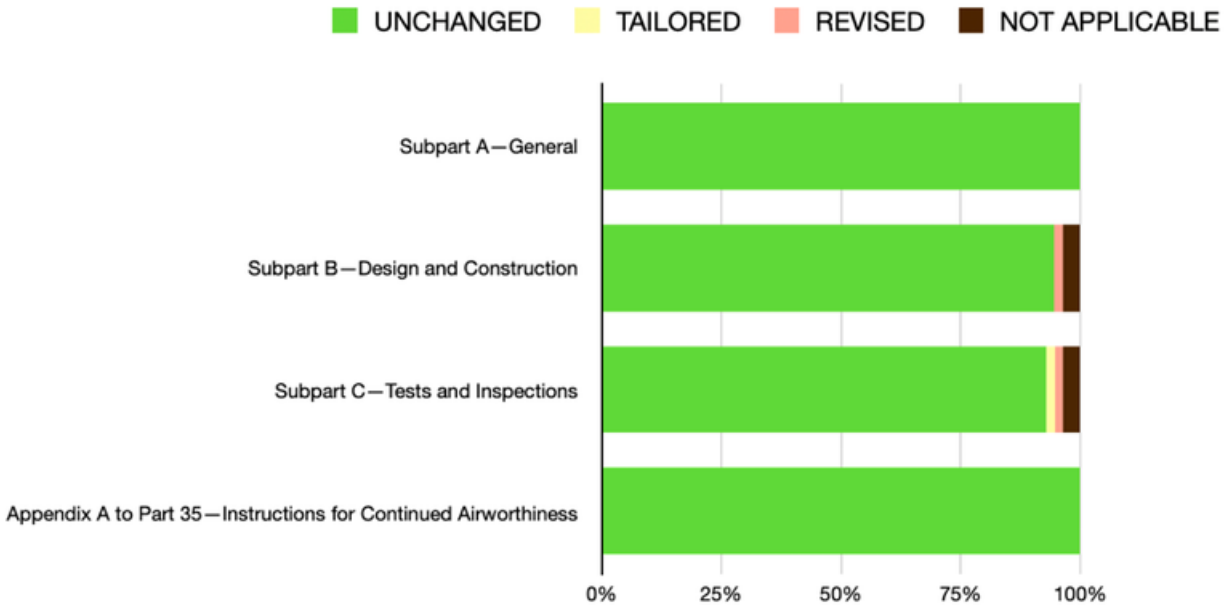


Figure 10 – Generic gap analysis of propellers for hybrid-electric turboprop.

Table 1, shows the top-3 subparts of each of the generic gap analyses. The results can be summarized as aircraft engines (covering general, design & construction, and block testing, in essence, every core element of an electric engine), energy storage systems (from 14 CFR Part 25 and 23 experience with lack of explicit battery standards in Subpart E, Powerplant), wiring and connectors (from 14 CFR Part 25, Subpart H, EWIS), and aircraft integration (from 14 CFR Part 25, Subparts E, F and G).

Table 1 – Highest priority subparts from the generic gap analysis by each airworthiness standard.

Airworthiness Standards Assessed Under 14 CFR	**Top-3 Subparts**
Normal Category Airplanes (Part 23)	• Subpart E, Powerplant • Subpart F, Equipment • Subpart G, Flightcrew Interface and Other Information
Transport Category Airplanes (Part 25)	• Subpart E, Powerplant • Subpart F, Equipment • Subpart G, Flightcrew Interface and Other Information *Note: Subpart H, Electrical Wiring Interconnection Systems, and Appendix L, HIRF should also be assessed*
Aircraft Engines (Part 33)	• Subpart A, General • Subpart B, Design and Construction • Subpart F, Block Tests; Turbine Aircraft Engines
Propellers (Part 35) *Turboprop Only*	• Subpart B, Design and Construction • Subpart C, Tests and Inspections

The EPFD R&SD team successfully applied the gap analysis methodology to pre-competitive turboprop and turbofan integrated MW-Class Powertrain Systems technologies. This laid a framework by which gaps in the regulation and standards could be identified by analysis that would balance the similar analysis conducted by the NASA-Industry partners. Examining pre-competitive technology enables adoption of the new technology by ensuring the development of standards without revealing proprietary technology.

The specific results were not shared with the potential industry partners, to ensure that their gap analysis was not prejudiced to replicate the NASA analysis, as NASA was focused on examining the industry partners approached, not trying to push the NASA generic approach. However, the R&SD team did produce a webinar that described what was sought, but without supplying any details. All of the potential industry partners were part of the webinar.

The generic gap analysis allowed for the NASA EPFD R&SD team to organize and prioritize the work necessary in SDOs to build industry standards for Means of Compliance (MOC) to regulations that do not yet exist and would be part of potential special conditions under 14 CFR Part 21.17(b). This ensures that EPFD could actively engage in those critical working groups in the SDOs associated with gaps in the current regulations. Secondly, it provided a means of articulating, for our potential industry partners, an approach EPFD wanted to see from the industry partners' approach to identifying regulatory gaps. This made certain to EPFD that their active participation in the SDO working groups was focused on their product-specific gap analysis.

4.3 Independent Assessments of the Generic Regulatory Gap Analysis

In 2025, the EPFD R&SD team had subject matter experts, who are a Designated Engineering Representative (DER), to review the generic regulatory gap analyses. These were conducted for Electric Engines (14 CFR Part 33 and associated Special Conditions), Powerplant (14 CFR Part 25, Subpart E), and Electrical Wiring Interconnect Systems (EWIS), Part 25, Subpart H.

The summary of the electric engine DER was that experience in industry committees such as SAE and ASTM influenced the custom written airworthiness criterion written for the certification basis. As the certification basis includes 14 CFR 23 Amendment 64 performance-based regulatory content, detailed means of compliance were generated to more specifically define the compliance requirements for each regulation. The means of compliance process was used for all the airworthiness criterion not just the regulations of 14 CFR 23 Amendment 64. In many cases the means of compliance used industry committee publications for specific technical content. In moving forward, existing published certification bases, and industry committee publications would be an efficient way to initiate the generation of new regulatory content for electrified propulsion systems.

The following fundamental research, and in particular testing-based work, is recommended to address Powerplant.

- A comprehensive investigation of new and novel failure modes of electric and hybrid-electric engines is warranted. While work done by individual applicants have uncovered a number of specific new failure modes, this information may not be comprehensive, as engine OEMs focus on showing compliance to the stated requirements, as opposed to conducting a broad-based failure mode and effects demonstration testing, unless required to do so by the certifying authority.
- In particular, further work is required to assess any new common-cause and propagating failures, and the required isolation means to mitigate their effects.
- Test-based fire threat characterization work for electric engines is recommended to ensure the levels of protection offered by Fire Withstanding Zones maintains the overall level of safety commensurate with the existing Transport category aircraft fleet. It is noted that testing performed by engine applicants has led to divergent conclusions in terms of the likely worst-case scenarios, hence a more comprehensive test campaign would help to inform the detailed requirements.
- While regulators, aircraft applicants, and battery OEMs have spent considerable time and resources on the battery thermal runaway threat, further work is required to confirm the events in terms of their energy, duration, flame size, etc., if standardized requirements are to be achieved. In addition, agreement is necessary on the means of determination of how many battery cells can be expected to go into thermal runaway (in absence of external common cause events).
- In particular, the issue of potential thermal runaway following an emergency or crash-landing needs further investigation to inform the crashworthiness requirements for Part 25 aircraft, to ensure successful egress of occupants and crew.
- The issues of energy dumping, dissipation and regeneration need further investigation and testing to inform the emergent standards and requirements.

The FAA's Part 25 Subpart H regulations (14 CFR §25.1701–25.1733) [19] establish a comprehensive framework for EWIS certification. The existing rules, when diligently applied, are adequate to cover high-voltage EWIS, as long as the implications using HV EWIS are understood. This understanding can be supplemented through test data and/or industry consensus standards/guidance.

FAA Advisory Circular (AC) 25.1701-1 [20] and the industry's best practices provide a solid certification basis for high-voltage EWIS, even though these rules were conceived before the current wave of electrification. There are certainly some gaps in the sense that new phenomena like partial

discharge were not explicitly named in subpart H. The onus is on the applicant and regulators to apply these rules with the high-voltage context in mind. EASA's special conditions for electric VTOL and SAE's new HV aerospace standards are complementing the FAA's framework, and it is expected that guidance material will continue to be updated to codify acceptable means of compliance for HV EWIS.

4.4 Gap Analysis of the FAA and EASA Special Conditions

In 2025, a regulatory gap assessment of the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA) Special Conditions (SC) for electric engines was conducted. This information is presented for inclusion in the ongoing international harmonization efforts for electric engine certification, with the aim of establishing a level of safety consistent across regulatory bodies and equivalent to that of existing combustion engines.

4.5 Key Technologies Areas for Regulations and Standards

In general, there are four key areas that EPFD and its industry partners are focused on: (1) Electric Engines, (2) Energy Storage Systems, (3) Wiring and Connectors, and (4) Airplane Integration. Figure 11 shows these four key areas, the relevant SDOs, and key efforts in working groups within the SDOs. The work that NASA has contributed to the SDOs (highlighted in the middle column) is in the working groups summarized in the last column of the figure. As noted, NASA SMEs have not only participated in the working groups but also in leadership positions as part of their contributions.

Electric Engines		ASTM F39.05 SAE E-40 IEC 61439-4	• PMM Tests supporting HV cable loads • Continued development of ASTM F3338 Standard Specification for Design of Electric Engines
Energy Storage Systems		ASTM F39.05 SAE AE-10 RTCA DO-311	• Chaired task group to develop AS7499, Power Quality for HV systems (SAE AE-10) • Co-chairing New Guide for Design and Production of Energy Storage Systems to Power Aircraft Propulsion (ASTM F39)
Wiring & Connectors		SAE AE-10 SAE AE-7	• Cable tests to support HV standards for AE-10 High Voltage Committee and AE-7 Aerospace Electrical Power and Equipment Committee (SAE) • Began work on on Arc fault detection requirements and technology (SAE)
Airplane Integration		SAE E-40 ASTM F44 RTCA DO-160	• Contributed to ARP8677, Safety Considerations for Electrified Propulsion Aircraft (SAE) • Leading Powerplant working groups on the installation of propellers for electric engines, ASTM • Leading Powerplant Displays for electric engines

Figure 11 – Four key technology areas, their associated standards committees, and NASA contributions in key areas.

4.6 Sharing Insights and Challenges – The Regulations and Standards Working Group

The EPFD R&SD team developed the Regulations and Standards Working Group (RASWG) to gather NASA research subject matter experts (SME) to contribute to SDOs. The FAA participates as a member of the various SDOs that are associated with the FAA certification policy for which the FAA is responsible. Uniquely, the EPFD RASWG brought in SMEs from across NASA projects, in addition to EPFD, to provide their expertise to develop standards. The following ARMD programs and projects contribute their electric aircraft propulsion expertise to the RASWG: Airspace Operations and Safety Program (AOSP)—Advanced Air Mobility (AAM) and System-Wide Safety (SWS); Advanced Air Vehicles Program (AAVP)—Advanced Air Transport Technology (AATT), Hi-rate Composite Aircraft

Manufacturing (HiCAM), Hybrid Thermally Efficient Core (HyTEC), and Revolutionary Vertical Lift Technology (RVLT); TACP—Solid-state Architecture Batteries for Enhanced Rechargeability and Safety (SABERS) and Subsonic Single Aft eNgine (SUSAN); and Integrated Aviation Systems Program (IASP)—Flight Demonstrations and Capabilities (FDC), X-57 Maxwell. In addition to the NASA SMEs participating in the RASWG, the working group also reaches out to the industry partners, and others in the EAP industry.

Furthermore, other electrification industry leaders engaged with the RASWG to discuss their R&SD activities with EPFD. The RASWG engaged with the FAA in two ways. The engagement with the Certification Policy specialists was predominantly through the SDOs. The engagement with the FAA Research specialists was as active members of the RASWG with their research questions and results incorporated with the NASA EPFD research objectives. These were typically the result of topics that arose during SDO meetings. Figure 12 shows the relationships of the various stakeholder SDOs, FAA, and NASA projects, where EPFD R&SD led the formation of two-way engagement avenues with FAA Certification Policy developers and SDO committees. Through the RASWG, EPFD, and NASA, EAP SMEs and the EAP industry engaged to discuss activities of interest and discuss topics being addressed in SDO committees, where the FAA Certification and Policy developers participate as members. The EPFD R&SD Leadership also directly engaged with the FAA Certification and Policy developers on priority gaps and means of compliance strategy and knowledge sharing.

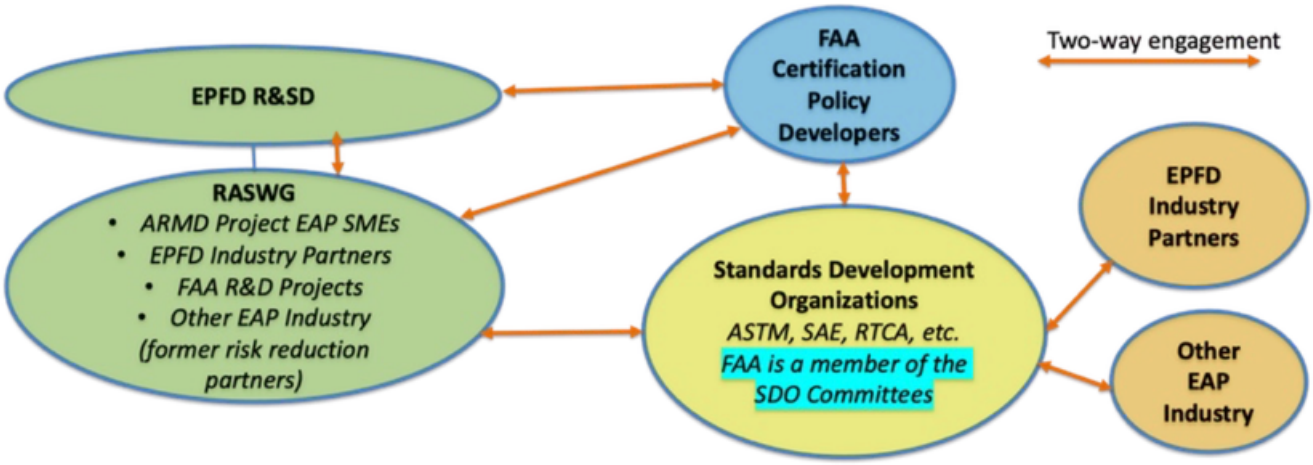


Figure 12 – Effective relationships established in standards development.

The result of building an integrated RASWG where coordination between the NASA SMEs and the industry and regulatory in EPFD is reflected in the increased number of standards that have been developed since the EPFD's inception. Figure 13 shows the number of current standards in development, organized by the highest priority regulatory gap technologies (see Table 2). Over 35 standards have been developed since EPFD started in 2020. Ten in 2024, alone.

This is not to overstate the contributions of EPFD compared to the needs of the industry and regulatory authorities. Rather, it reflects the interest in an integrated MW-class powertrain system and the need to implement MOCs in anticipation of entry into service.

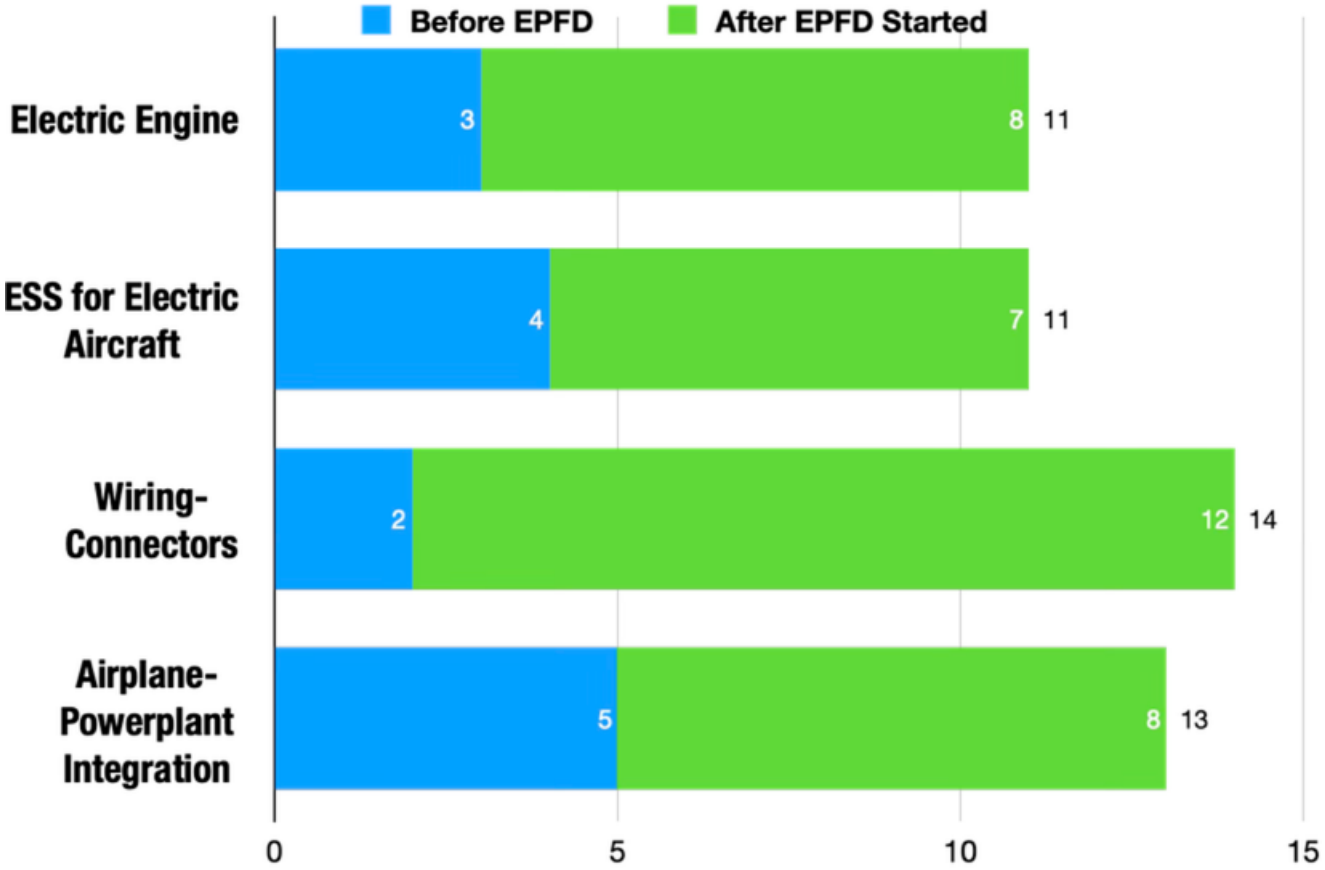


Figure 13 – Number of current standards in development by highest priority technology gap.

4.7 Digital Engineering Tools for Regulatory Gap Analysis

While the traditional approach to regulatory gap analysis is well documented, the EPFD R&SD team invested in an alternative approach to regulatory gap analysis using a novel application of model-based systems engineering (MBSE) analysis. The Georgia Tech Aerospace Systems Design Lab (GT ASDL) developed a method that examined each paragraph of the US FAA regulations and sought to find differences between references to physical and functional attributes of technologies in the regulations. The GT-ASDL team ingested Parts 23, 25, 33, and 35 and the associated standards for those regulations into their MBSE analysis system. In addition, the GT-ASDL team identified functional attributes of the regulatory citations. An example of the GT-ASDL team's results [21] is shown in Figure 14, which depicts the Powerplant subpart of the transport category airplane regulation (14 CFR Part 25, subpart E, Powerplant) on two different EAP architectures. The figure shows a conventional four-engine turboprop architecture in the first bar chart [22] labeled "Conventional" and compares it to two different EAP architectures. A functional attribute of a fuel tank in the regulations is considered "energy storage." Thus, for an EAP, while the functional attribute is considered energy storage, the physical attribute of an EAP is a Battery (or engine-generator, or hydrogen fuel cell, etc.), and the mismatch is identified as a "gap." That way, the GT-ASDL team could observe where the first-order gaps exist in the regulations for a given architecture when there is a mismatch between the physical and functional attributes. This MBSE methodology provided a structured and repeatable approach to regulatory gap analysis that benefited the dialog with the FAA and laid a structured approach to standards development.

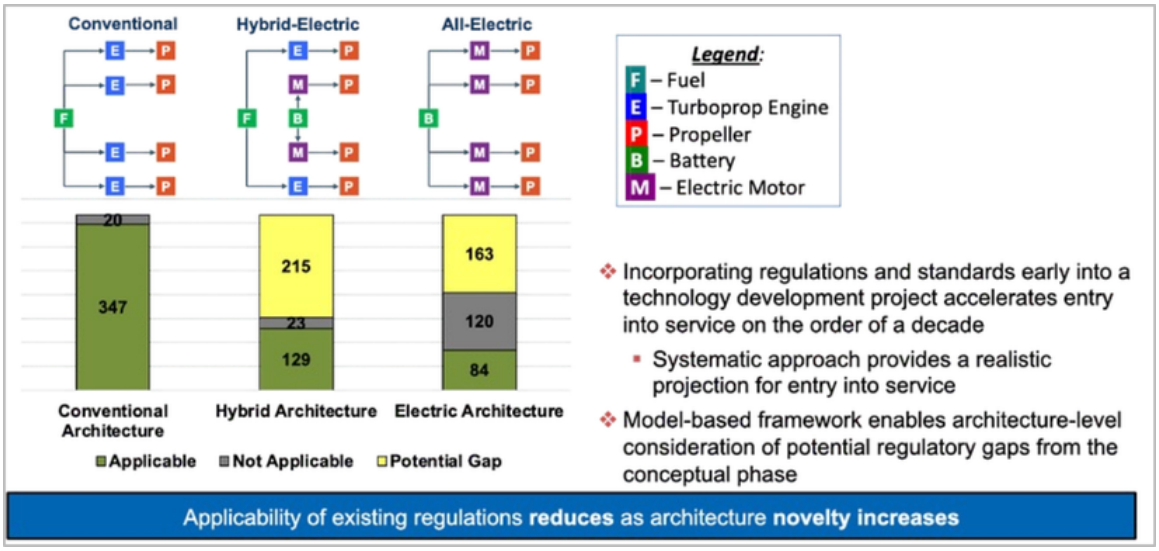


Figure 14 – GT MBSE demonstrated automated regulatory gap analysis.

5. Building Standards to Fill the Regulatory Gaps of Novel EAP

5.1 Linking Technology Development with Standards Development

The EPFD R&SD team has established a Standards Maturity Level (SML) to assess the maturity of standards in the development process. It follows the typical methodology used by SDOs, which is roughly organized by standard formulation, scrutinizing the proposed standard, and finally implementing it. Table 2 shows the definitions, categories, and notes to apply to standards as they mature from formulation at the technologists' level through vetting between the SDO and the technologist, and ultimately become published standards.

Table 2 – EPFD standards maturity level (SML) framework.

ID	Definition	Category	*Notes*	*Role*
SML 9	Standard has been published by SDO	**Implementing**	*The technical document goes through publication review and is published.*	*The SDO publishes.*
SML 8	Standard passes full committee ballot and is submitted as full standard		*After one or many ballots in the Committee, the ballot returned with no negatives, and the standard is ready.*	***Standards** & **technical specialists** draft ballots and disposition negatives*
SML 7	Working Group drafts the standard in the form of a full committee ballot		*Send out the working group's product for review by the full committee.*	***Standards** & **technical specialists** compose first draft*
SML 6	Standard passes subcommittee ballot and is submitted as full committee ballot	**Vetting**	*After one or many ballots within the subcommittee/ task group, the standard is deemed ready for full committee actions*	***Standards specialist** develops a full committee ballot*
SML 5	Working Group drafts the standard in the form of a subcommittee working group ballot		*Send out the working group's product for review by those outside of the working group*	***Standards specialist** drafts subcommittee ballots for comment*

ID	Definition	Category	*Notes*	*Role*
SML 4	Terms of Reference are accepted by an SDO and assigned to a committee with a working group and subcommittee		*Build a working group and begin the development of a new or revised standard*	***Standards specialist*** *and* ***technologist*** *recruit talent to populate a working group*
SML 3	Terms of Reference are marketed to various SDOs. Assess the SDO expertise and ability to fit into an appropriate committee within the SDO	**Formulating**	*Where does the standard fit? Does the SDO have the expertise?*	*The* ***technologist*** *identifies proposed SDOs for the draft standard working with a standards specialist*
SML 2	Terms of Reference (ToR) are drafted for potential standard.		*Does the gap identify a guide, test practice, standard, information report, etc.?*	*The* ***technologist*** *develops a draft ToR for a standard*
SML 1	Regulatory Gap Analysis IDs gaps in standards based on technology demonstrated that does not have a Means of Compliance		*First step. Is the gap in the regulations or in the standards, or both?*	*The* ***technologist*** *develops a draft gap analysis based on the proposed technology and its intended use.*

The SML describes the progression of a standard as it moves from its formulation as a result of a novel technology (that does not conform to current standards) to the development of a draft standard based on the novel technology (vetting it through peer-assessed scrutiny), and finally publishing a standard by implementing a standard development organization's review and publication processes.

The SML is a tool that connects novel technology development to its certification. Here, novel technology is defined as being developed at Technology Readiness Levels [1] (TRL) 4-6, which typically includes technologies validated in a lab or relevant environment, up to those demonstrated in a relevant usage context. From a certification standpoint [23], a novel technology concept would be articulated in the Partnership for Safety Plan (PSP) agreement, initially serving as a straightforward roles and responsibilities document that expands as the Applicant refines its processes. The SML serves as a structured approach to identify necessary standards to develop comprehensive means of compliance, methods of compliance, practices, or testing procedures, ensuring the confident certification of novel technology by both the Applicant and regulatory authorities.

5.2 Identifying the Highest Priority Standards

The highest priority regulatory gaps are shown by the four technologies in Figure 11. Those four swim lanes are (1) Electric Engines, (2) Electric Storage Systems, (3) Wiring and Connectors, and (4) Airplane Integration. The applicable, highest priority standards for Electric Engines are shown in Table 3, for Energy Storage Systems in Table 4, for Wiring and Connectors in Table 5, and for Airplane Integration in Table 6. These standards will evolve to become the means of compliance to address current gaps in civil aviation regulations.

Table 3 – Current standards for electric engines.

SDO	Committee	Document	Title	Sponsor	Date	SML
ASTM	F44.40	F3239	Revision of F3239-18 Standard Specification for Aircraft Electric Propulsion Systems	Herb Schlickenmaier	May 14, 2020	5
ASTM	F44.40	F3063	Revision of F3063/F3063M-21 Standard Specification for Aircraft Fuel Storage and Delivery	Christoph Genster	Nov 2, 2021	3
ASTM	F39.05	F3338	Revision of F3338-21 Standard Specification for Design of Electric Engines for General Aviation Aircraft	Tom Gunnarson was Peter Lyons	Jul 8, 2022	9
ASTM	F39.05		Design of Hybrid-Electric Powerplants for General Aviation Aircraft	David Eichstadt	Sep 28, 2022	5
SAE	AE-10	ARP7159	System level Protection and Coordination in High Voltage aerospace applications	Kolten Miller	Apr 2, 2024	4
SAE	AE-10	AS7499	Aircraft High Voltage DC Power Quality Standard	David Sadey	Jun 5, 2019	7
SAE	AE-10	AS8441	Minimum Performance Standard for Permanent-Magnet Propulsion Motors and Associated Variable-Speed Drives	Mikhail Goykhman	Jun 4, 2018	7
SAE	E-40	ARP8582	Durability Tests for Aircraft Electric Engine	Zachary Kaufman	Dec 10, 2024	4
SAE	E-40	AIR7128	Integration and Certification Considerations for Electrified Propulsion Aircraft	Juan Carlos Parra Gila	Oct 3, 2022	5
SAE	E-40	ARP8689	Endurance tests for Aircraft Electric Engine	Yves Cousineau	Mar 8, 2021	4
SAE	E-40	AIR8677	Safety Considerations for Electrified Propulsion Aircraft	John Ostic	Apr 2, 2019	5

Table 4 – Current standards for energy storage systems.

SDO	Committee	Document	Title	Sponsor	Date	SML
ASTM	F39.05		Design and Production of Energy Storage Systems to Power Aircraft Propulsion	Kevin Bruce	Jun 14, 2017	4
ASTM	F44.40	F3239	Revision of F3239-18 Standard Specification for Aircraft Electric Propulsion Systems	Herb Schlickenmaier	May 14, 2020	5
ASTM	F39.01		Installation of Rechargeable Lithium Batteries on Aircraft	Brett Williams	Jan 21, 2022	9
ASTM	F39.05		Design of Hybrid-Electric Powerplants for General Aviation Aircraft	David Eichstadt	Sep 28, 2022	5
SAE	AE-10	AIR7152	High Speed Permanent Magnet Generator for Aerospace Applications	Ellis Chong	Mar 8, 2024	4
SAE	AE-10 (Shared)	AS6087	ARC Fault Interrupter, 270 VDC	Josh Swenson	Apr 27, 2019	7
SAE	AE-7A	ARP6505	Electrical Load Analysis (ELA) Standardization	Nicholas Bunt	Jul 18, 2017	5
SAE	AE-7D	AIR8487	Offboard thermal management system coupler for electric aircraft charging and preconditioning	Theodore Bohn	Nov 1, 2024	4
SAE	AE-7D	AIR7357	MegaWatt and Extreme Fast Charging for Aircraft	Theodore Bohn	Nov 20, 2020	4
SAE	E-40	AIR7128	Integration and Certification Considerations for Electrified Propulsion Aircraft	Juan Carlos Parra Gila	Oct 3, 2022	5
SAE	E-40	AIR8677	Safety Considerations for Electrified Propulsion Aircraft	John Ostic	Apr 2, 2019	5

Table 5 – Current standards for wiring and connectors.

SDO	Committee	Document	Title	Sponsor	Date	SML
ASTM	F44.40	F3239	Revision of F3239-18 Standard Specification for Aircraft Electric Propulsion Systems	Herb Schlickenmaier	May 14, 2020	5
SAE	AE-10	AIR7146	Isolation failure development in high voltage battery systems	Nathaniel Wynn	Sep 7, 2023	4
SAE	AE-10	AIR7258	Pyrotechnic actuator for fast action as electrical protection in HVDC aerospace application	Philippe Naneix	May 2, 2023	4
SAE	AE-10	AIR7255	Safety and Reliability of High-Voltage Electrical Wiring and Interconnect Systems	William Ritner	Apr 3, 2023	4
SAE	AE-10	AIR7136	Insulation Monitoring Devices	Florian Bruder-Mandler	Mar 15, 2023	4
SAE	AE-10	ARP7135	Guide for Electric Load Analysis and Power Source Capacity Planning in High Voltage Electric Power Systems	Slava Khozikov	Mar 6, 2023	4
SAE	AE-10	ARP7215	Aerospace Conductor Surface Spacing on Dielectric Material	Christopher Severns	Nov 1, 2022	5
SAE	AE-10	ARP7376	Design And Test of High Voltage Power Electronic equipment	Andrew Benn	Oct 20, 2022	5
SAE	AE-7D	AIR8487	Offboard thermal management system coupler for electric aircraft charging and preconditioning	Theodore Bohn	Nov 1, 2024	4
SAE	AE-7D	ARP8486	Global Electric Aviation Charging System	Paul Guerra	Sep 24, 2024	4
SAE	AE-7D	AIR7357	MegaWatt and Extreme Fast Charging for Aircraft	Theodore Bohn	Nov 20, 2020	4
SAE	AE-7D	AS6968	Connection Set of Conductive Charging for Light Electric Aircraft	Joshua Portlock	Feb 7, 2019	
SAE	E-40	AIR7128	Integration and Certification Considerations for Electrified Propulsion Aircraft	Juan Carlos Parra Gila	Oct 3, 2022	5
SAE	E-40	AIR8677	Safety Considerations for Electrified Propulsion Aircraft	John Ostic	Apr 2, 2019	5

Table 6 – Current standards for airplane integration.

SDO	Committee	Document	Title	Sponsor	Date	SML
ASTM	F44.40	F3239	Revision of F3239-18 Standard Specification for Aircraft Electric Propulsion Systems	Herb Schlickenmaier	May 14, 2020	5
ASTM	F44.40	F3066	Revision of F3066/F3066M-18 Standard Specification for Aircraft Powerplant Installation Hazard Mitigation	Herb Schlickenmaier	Jun 24, 2019	4
ASTM	F44.40	F3064	Revision of F3064/F3064M-18a Standard Specification for Aircraft Powerplant Control, Operation, and Indication	Herb Schlickenmaier	Jun 24, 2019	4
ASTM	F44.40	F3063	Revision of F3063/F3063M-21 Standard Specification for Aircraft Fuel Storage and Delivery	Christoph Genster	Nov 2, 2021	3
ASTM	F39.01		Installation of Rechargeable Lithium Batteries on Aircraft	Brett Williams	Jan 21, 2022	9
SAE	AE-10	AS7499	Aircraft High Voltage DC Power Quality Standard	David Sadey	Jun 5, 2019	7
SAE	AE-7A	ARP6505	Electrical Load Analysis (ELA) Standardization	Nicholas Bunt	Jul 18, 2017	5
SAE	AE-7D	AIR8487	Offboard thermal management system coupler for electric aircraft charging and preconditioning	Theodore Bohn	Nov 1, 2024	4
SAE	AE-7D	ARP8486	Global Electric Aviation Charging System	Paul Guerra	Sep 24, 2024	4
SAE	E-40	AIR8639	Electrified Propulsion Aircraft Ingestion	Edward Lovelace	Oct 10, 2024	4
SAE	E-40	AIR7128	Integration and Certification Considerations for Electrified Propulsion Aircraft	Juan Carlos Parra Gila	Oct 3, 2022	5
SAE	E-40	AIR8677	Safety Considerations for Electrified Propulsion Aircraft	John Ostic	Apr 2, 2019	5
SAE	G-35	ARP7094	Modeling and Simulation to support certification of aircraft and avionics	Antony Hunt	Jun 22, 2022	4

A summary of the active standards development organization working groups and works-in-progress is illustrated in Table 7. The current efforts are focused on vetting standards for MOCs in time for implementation.

Table 7 – Summary of active standards in development by technology and maturity level.

EPFD EAP Priority Systems	Before EPFD	After EPFD Start	Started in 2024	Standards Maturation Level (SML) Range for After EPFD Start (number of standards)			Total in Work
				Formulation	Vetting	Implementation	
Electric Engine	3	8	2	1	6	1	8
ESS for Electric Aircraft	4	7	3	0	6	1	7
Wiring-Connectors	2	12	2	0	12	0	12
Airplane-Powerplant Integration	6	8	3	1	6	1	8

6. Conclusions, Lessons and Future Research

To answer what it takes to certify an electric aircraft, the EPFD project collected lessons and practices of use for electric aircraft entrepreneurs. First, understanding is needed of the certification practices regulatory authorities use in the face of gaps in the current regulations and knowing how performance-based regulations are approached through the special condition processes. Second, the EPFD R&SD team found that, for special condition processes, it is best to build means of compliance through the standards development organizations worldwide. This is how the regulators can see the rationale for proposed standards to be used as a means of compliance. It also means that electric aircraft entrepreneurs must engage in the standards that most affect their concept, and the successful companies are those that are engaged. Finally, the regulatory gap analysis should be built early and kept fresh during the development cycle, which includes understanding the highest priority gaps that must be addressed immediately. The use of digital engineering tools can ensure not only the timeliness of the refresh but also the consistency of the gap analysis over time and lessons from testing. Sharing this prioritized gap analysis with the regulatory authorities' policy organizations ensures that the regulatory authorities' lessons can be shared with entrepreneur applicants. These are all lessons and practices that the NASA EPFD project has gathered as of the time of this paper.

In the X-57 project, we cut our teeth on *HOW* to do a gap analysis, but the gap analysis could not inform the project as it was already long past PDR and CDR and deep into execution and preparation for flight demonstration. Life cycle reviews were the focus, while standards development was given lip service and subsequently neglected. The EPFD project was a unique opportunity to leverage the lessons of how to do a gap analysis, and embed the practice during the EPFD project formulation (doing a generic hybrid electric, Part 25 airplane with the associated Part 33 aircraft engine assessment). The EPFD project was able to share the experience and approach with potential industry partners to embrace as part of their proposal submittal. Kudos to the project leadership of EPFD for embracing the benefits of early regulatory gap analysis in project formulation. Once in execution, the industry partners were able to share their unique R&SD approaches to the project and thus direct the data collection to support the development of standards for MOCs.

The EPFD project demonstrated that a robust R&SD element, working closely with the FAA through SDOs, is crucial in developing standards to address regulatory gaps, thereby enabling the entry into service of electrified integrated MW-class powertrain system aircraft in the mid-2030s. As EAP, in its various forms, including advanced air mobility, ultra-short take-off and landing, and wing-borne vertical lift, attempts to enter into service, these novel EAP vehicles must build a close working relationship between their technology development and certification planning. The EPFD project is issuing a call to action to industry, SDOs, and regulatory authorities to develop standards that enable the certification of all varieties of EAP aircraft, concurrent with the technology's maturation.

There are four areas for future work:

- *Apply the Standards Maturity Level (SML) to technology development projects.* The benefit demonstrated during EPFD allows for tracking the progress of standards development and sets the foundation for its application in other projects.
- *Integrate a Regulations and Standard Working Group (RASWG) as a cross-cutting technology infusion into the standards development process.* Gathering diverse technology specialists in standards development is a *Best Practice* and was an important tool for rapidly advancing standards development in the EPFD project. The ability of a technology specialist to provide data to a standards development working group is an invaluable contribution. As an example, the benefits demonstrated during the EPFD project in EMI and power quality was priceless.
- *Integrate technology data collection from both ground and flight tests in flight demonstration projects into the development of standards.* This integration is vital, as assessing changes to test practices that were affected by EAP testing to develop changes to those test practices is a key tool for the continued improvement of test guidelines and practices for standards. The full integration of data collection into a comprehensive, systems engineering framework, based on the requirements to close regulatory gaps, is a best practice.
- *Use digital engineering tools to accelerate the investigation of regulatory gap assessment.* The Model-Based System Engineering effort that the Georgia Tech Aerospace Systems Design Laboratory pioneered and innovated should be continued. The foundation is solid and has been applied across the regulatory parts. In the near term, it has demonstrated the ability to expedite the regulatory gap assessment process. This work has the potential to evolve into a design element in the systems analysis toolbox, together with aerodynamics and propulsion elements. In the long term, this effort could revolutionize the design of novel vehicle concepts and their trade-offs.

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[13] 14 CFR Part 23, Normal category airplanes, and Part 25, Transport category airplanes. Also European CS-23 and CS-25.

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[20] FAA Advisory Circular AC 25.1701-1. Certification of electrical wiring interconnection systems on transport category airplanes. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_25_1701-1.pdf.

[21] The example labeled “Conventional” depicts how the fuel (“F”) is fed into the turboprop engine (“E”), which drives the propellers (“P”). There are 367 citations in the regulations and 347 of them are applicable (the 20 that are gaps are associated with turbine engines, for example). The Hybrid-Electric example depicts a conventional architecture augmented by two electric motors (“M”) powered by a battery (“B”), each of which drives a propeller. In this case, there are 215 potential gaps in the 367 cited regulations that are identified as having a difference in functional and physical attributes. In the All-Electric example, the number of potential citation gaps is 163 with 120 are no longer applicable.

[22] The 20 “not applicable” citations out of the 367 total citations for the Conventional Architecture in Part 25, Subpar E, refer to Reciprocating Engine regulations, which are not applicable to a turboprop.

[23] FAA and Industry Guide to product certification. 3rd ed. Prepared by AIA, AEA, GAMA, and the FAA Aircraft Certification Service and Flight Standards Service, May 2017.