A CALL TO ACTION TO ENGAGE THE COMMUNITY TO MEET THE CHALLENGES THAT MUST BE TACKLED TO MAKE ELECTRIFIED AIRCRAFT PROPULSION REAL

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Abstract

Technology risk reduction is essential, as it is necessary to demonstrate the potential of Electrified Aircraft Propulsion (EAP). However, more is needed for implementation. The industry is leading EAP by developing a diverse community of novel vehicles from short-haul, small, urban-focused electric vertical takeoff and landing (eVTOL) to regional air mobility (RAM) and hybrid-electric, single-aisle transport category airplanes. There are a variety of novel EAP technologies for each of these novel vehicles. *Industry* is not only looking at novel technology to advance the state of the art, it is looking to certify these novel aircraft through their regulatory authorities, such as the US Federal Aviation Administration (FAA), the European Union Aviation Safety Authority (EASA), Transport Canada Civil Aviation (TCCA), and Brazil's Agência Nacional de Aviação Civil (National Civil Aviation Agency, ANAC), as well as other regulatory authorities. The NASA Electrified Powertrain Flight Demonstration (EPFD) project has partnered with two industry partners to advance integrated MW-class powertrain system technology and assess their regulatory and standards gaps in their technology. The EPFD project has conducted a generic regulatory gap analysis of hybrid electric engines that aligns with the industry partners' efforts. The EPFD regulations and standards team is integrated into the industry standards community. The international industry standards community is wrestling with critical key challenges to certification. While some certification elements are proprietary, several technology elements cut across company propriety in aircraft engines (US 14 CFR Part 33 and EASA CS-E, regulations that only reflect reciprocating and turbine engines). The approach that several of these regulatory authorities have taken is to collaborate to address their challenges. The Certification Management Team (CMT) consists of the EASA, FAA, TCCA, and ANAC, and they have begun to address common questions, such as the Loss of Power Control (LOPC) for electric engines. They have reached out to the standards community to seek answers. The industry standards development organizations (SDO) have also looked ahead to address current regulations and standards gaps. The ASTM has built key committees in its ASTM F44 General Aviation Committee and F39 Aircraft Systems Committee. The SAE has established the E-40 Electric Propulsion and AE-10 High Voltage committees.

Keywords: Standards, Regulations, Certification, Novel Vehicles, Electric Engines

1. Background: What Drives the Electrified Powertrain Flight Demonstration Approach?

The Electrified Powertrain Flight Demonstration (EPFD) project has a unique relationship with the Federal Aviation Administration (FAA) based on the National Aeronautics and Space Administration's (NASA) Aeronautics critical commitment 3.1 to "…[demonstrate] practical vehicle-level integration of MW-class electrified aircraft propulsion systems, leveraging advanced airframe systems to reinvigorate the regional and emerging smaller aircraft markets and strengthen the single-aisle aircraft market…." Central to the critical commitment is "Electric Aircraft Propulsion (EAP) Regulations and Standards Gaps and Closure." Incorporating regulations and standards early into a technology development project accelerates entry into service on the order of a decade.

Within EPFD, the Regulations and Standards Development (R&SD) team is the focus and lead for working with the FAA.

Unlike the U.S. NextGen or the Single European Sky Air Traffic Management Research (SESAR) initiatives, the FAA and Eurocontrol are not in the position of leading technology innovations, and the interaction with the FAA and regulatory authorities worldwide is much more focused on engineering certification than operational certification. Each aircraft and electric engine manufacturer is innovating the technology and coming to the FAA in the US and the European Union Aviation Safety Agency (EASA) in Europe for their civil aviation certificates. Therefore, the FAA in the US needs to be able to adjust its approach to the Regulatory Procedures Act as the FAA faces certification projects from the industry.

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 Standards Development Organizations (SDO) such as the ASTM and SAE [1], with their focus on standards for means of compliance for aircraft and engine type certification activities.

Performance-based rulemaking (PBR), in the form of special conditions, has changed the role of standards work. Originally, standards organizations 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 1 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.

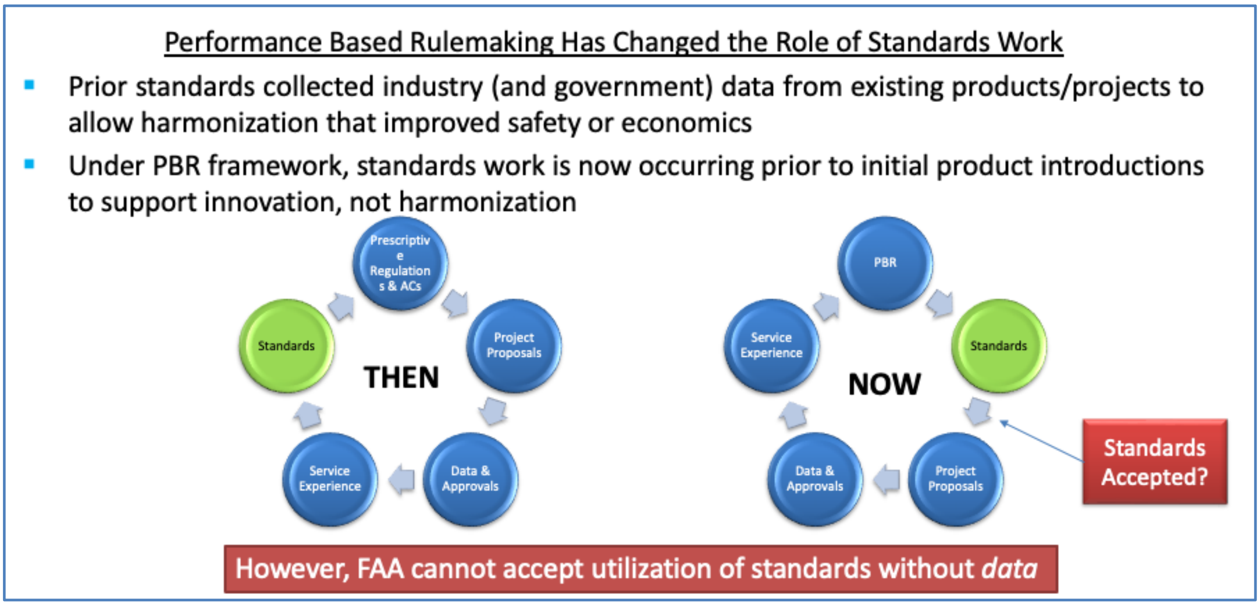


Figure 1 - The importance of data for today's standards (©2023, magniX)

2. Regulations and Standards NASA Engagement

The EPFD R&SD team developed key documents to describe the methodology expected of its industry partners. The first step was creating a regulatory gap analysis of a generic hybrid electric engine. This regulatory gap analysis examined all the elements in 14 CFR: Parts 25, Transport Category Airplanes; 33, Aircraft Engines; and 35, Propellers. The analysis goal 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. The objective was to organize and prioritize the work necessary in SDOs to build industry standards to be used as Means of Compliance (MOC) to regulations that do not yet exist and that 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 ensured EPFD that their active participation in the SDO working groups was focused on their product-specific gap analysis. 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 2 shows these four key areas, the relevant SDOs, and critical efforts in working groups within the SDOs. The work that NASA contributes to the SDOs (highlighted in the middle column) is summarized in the working groups in the last column of the figure. As noted, NASA SMEs are not only participating in the working groups but also in leadership positions as part of their contributions.

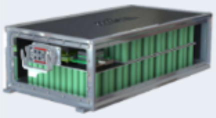
Electric Engines		ASTM F39.05 SAE E-40 IEC 61439-4	• PMM Tests supporting HV cable loads • Continued development of ASTM F3338 Standard Specification for Design of Electric Engines
Energy Storage Systems		ASTM F39.05 SAE AE-10 RTCA DO-311	• Chaired task group to develop AS7499, Power Quality for HV systems (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 2 - The four key technology areas, their associated standards, and the critical contributions from NASA EPFD SMEs

3. The EPFD Engagement Strategy

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, EASA, TCCA, and ANAC regulatory authorities participate in theSDOs. Uniquely, the EPFD RASWG brings in SMEs from across NASA projects in addition to EPFD to provide their expertise to develop standards. The following NASA Aeronautics Research Mission Directorate (ARMD) programs and projects contribute their electric aircraft propulsion expertise to the RASWG: Airspace Operations and Safety Program (AOSP) Air Mobility Pathfinder (AMP) 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); Transformative Aeronautics Concepts Program (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 two EPFD industry partners on particular topics.

Furthermore, other electrification industry leaders ,such as Ed Lovelace (chair of SAE E-40 and CTO of Ampaire) and others, engage with the RASWG to discuss their R&SD activities with EPFD. The RASWG engages with the FAA from the Certification Policy and FAA Research specialists. Figure 3 shows the relationships of the various stakeholder SDOs, FAA, and NASA projects, where EPFD R&SD has led the formation of two-way engagement avenues with FAA Certification Policy developers and SDO committees. Within the RASWG, the NASA team discusses topics being addressed in SDO committees and where the NASA team can contribute. The EPFD R&SD Leadership also directly engages with the FAA Certification and Policy developers on priority gaps and means of compliance strategy and knowledge sharing.

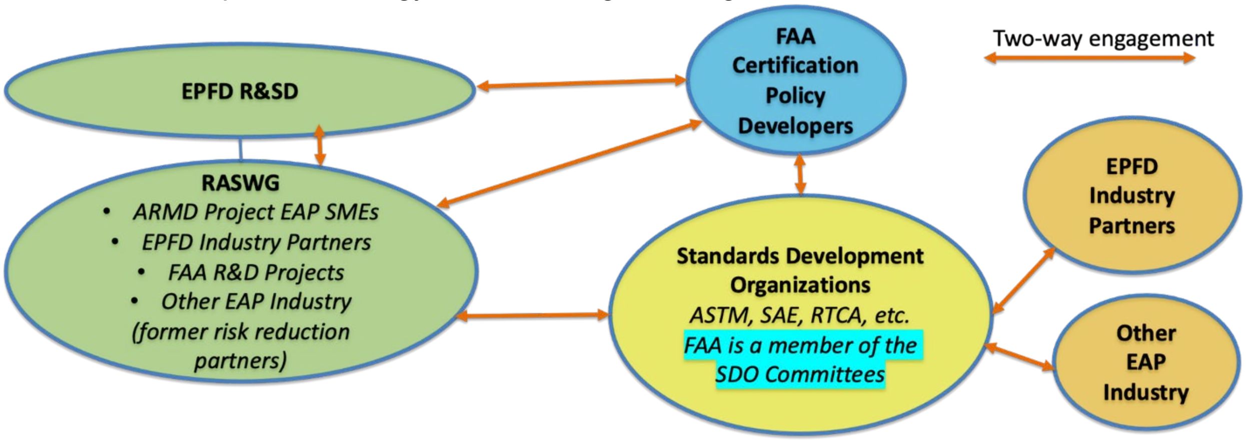


Figure 3 - Relationships Established in Standards Development

Foreseeing the new era of electric aircraft, NASA realized that the X-57 vehilce being developed under the FDC project could be used as an example case for standards discussions. Using the X-57 as an example vehicle for certification issues with novel aircraft technologies, the X-57 team assessed regulatory and standards gaps for a generic vehicle similar to the X-57 [2]. Based on the success of this approach to X-57, EPFD chose to use a similar process for integrated MW-class powertrain systems [3].

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 analysis (MBSE). 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 has ingested Parts 23, 25, 33, and 35, as well as the associated current standards for those regulations, into their MBSE system. In addition, the GT-ASDL team identified functional attributes of the regulatory citations. The EPFD Project's GT-ASDL team presented this approach at the June 2023 AIAA Aviation Forum which included the Electric Aircraft Technology Symposium (EATS in San Diego, California [4] [5]. An example of the GT-ASDL team's results is shown in Figure 4 [6]. The focus of this example analysis in the figure is the Powerplant subpart of the transport category airplane regulations (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 [7] 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 can see 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 provides a structured and repeatable approach to regulatory gap analysis that benefits the dialog with the FAA and lays a structured approach to standards development.

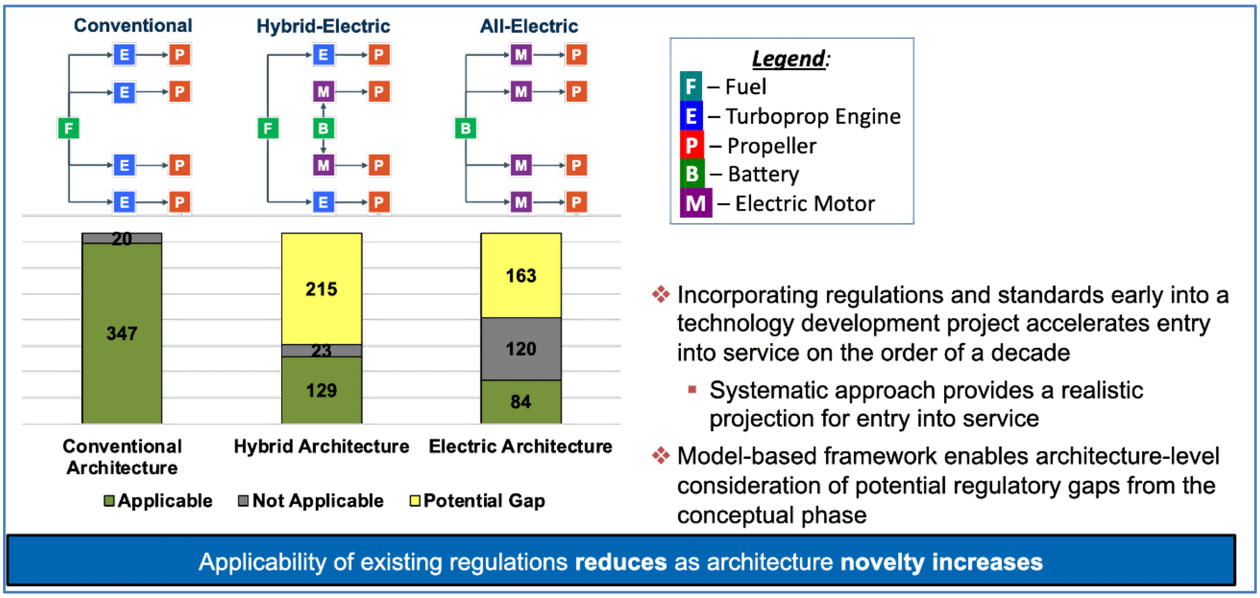


Figure 4 – GT-ASDL MBSE demonstrated automated regulatory gap analysis

4. The EPFD Regulations and Standards at the Close of 2023

The use of SDOs for the discussions with the FAA has been invaluable, and the EPFD R&SD team plans to continue this approach.

The RASWG sets the entry point for the NASA EPFD SMEs to engage with the SDOs, and the RASWG guides priorities to the EPFD objectives. The EPFD Team works with the FAA Policy Certification specialists active in the Standards community.

For electric engines, covering the significant gaps in 14 CFR Part 33, the FAA Policy Certification specialists are Mike Walz, and Mark Bouyer. They 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. Thus, the engineering data NASA EPFD brings with our partners, GE & magniX, are parts of the potential solution. The science requirements process that EPFD has developed with magniX, for example, will form a significant engineering due diligence foundation for addressing the gaps in the standards.

The FAA Policy Certification specialists are Jeff Pretz and Boyd Rodeman for 14 CFR Part 23, Subpart E, Powerplant for Powerplant installation and aircraft integration. This covers the powerplant installation knowledge gaps and barrier technical gaps, and it informs EPFD work in Part 25, Subpart E, Powerplant challenges. This covers energy storage systems for powerplants and power cabling for the energy storage system for powerplants. The FAA Policy Certification specialist in energy storage systems is Norm Pereira, who developed the RTCA DO-311 document for auxiliary power systems in Subpart G. EPFD is working with the industry in SAE AE-10 and ASTM F39 on energy storage systems for Powerplants.

The opportunity for EPFD R&SD to work with the regulatory authorities worldwide is made possible through the SDOs. In April 2024, the Certification Management Team (CMT) composed of Mark Bouyer, FAA, Régis Rossotto, EASA, Eric Fleurent-Wilson, Transport Canada Civil Aviation (TCCA), and Marcelo Saito, National Civil Aviation Agency (Agência Nacional de Aviação Civil, ANAC) Brazil, discussed their Task Specific Team (TST) on Loss of Power Control (LOPC). This online discussion was attended by hundreds of participants from around the world (including the two R&SD industry partners). It provided key insights into the current state of planning on the critical topic of LOPC and future challenges that the CMT may engage in.

The EPFD R&SD team also participates in an interagency Propulsion Power Systems Alliance (PPSA—born out of the turbine engine community) called the Hybrid-Electric Systems (HES). The PPSA meets and shares with the Government, and the FAA participates in the PPSA.

The EAP R&D community is wide-ranging and consists of both emerging and established engine manufacturers and novel EAP aircraft manufacturers engaged in flight demonstrations and certification projects across markets ranging from small regional passenger service to single-aisle transport aircraft. This past year, the FAA R&D team at the William J Hughes Technical Center contacted the EPFD R&SD team to participate in the EPFD RASWG. This allows the FAA R&D team at the FAA WJHTC to leverage the EPFD technology development expertise with their research expertise and facilities. The RASWG leadership works with Jonathan Doyle, the Electric Engine Test Facility manager, and his team, led by Dr. Tom Maloney, sharing their efforts in the SAE AE-10 and E-40 committees and ASTM F39 and F44.

This close working relationship between the FAA and NASA underpins the role EPFD has taken with the FAA through the standards development organizations and reinforces the benefit of such an approach to the benefit of the FAA and the industry. Figure 5 shows how the EPFD R&SD team has progressed from its beginnings and the development of the regulatory gap analysis for a generic hybrid EAP through its current efforts with the two industry partners by building science requirements into standards for magniX and the development of test standards for GE, all in the process of gathering data to develop and inform standards that will close regulatory gaps.

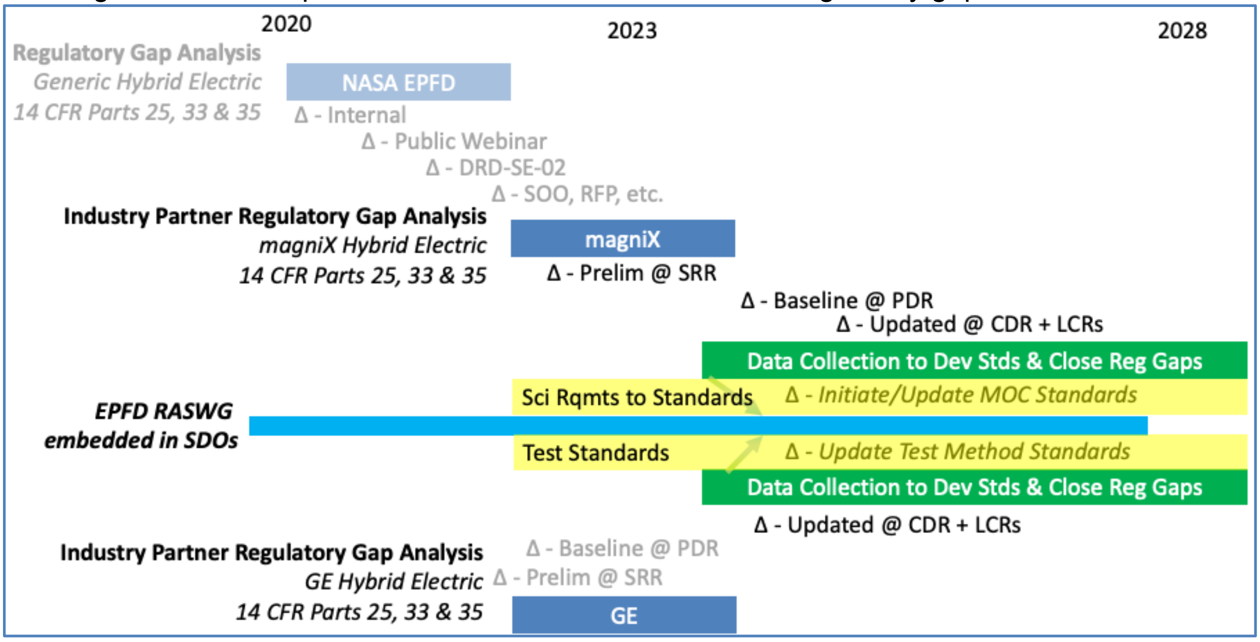


Figure 5 - Approach to gap closure: Analysis+Test

As EAP, in its varieties, enters into service, a close working relationship between EPFD R&SD and the FAA, through the SDOs, is critical in developing standards to fill regulatory gaps to enable the entry into service of aircraft electrification. For EAP to become a reality, it is imperative to develop the data to establish the standards that fill the gaps in the current regulations worldwide. The EPFD project is rallying a call to action by industry, the SDOs, and the regulatory authorities to make EAP a reality.

5. End Notes

[1] While traditional NASA research projects focus on operational improvements, we are in a time when novel aircraft are being developed and need to be certified, and the means of compliance to certify these novel aircraft are being developed in SDOs, together with the FAA, EASA, TCCA, ANAC, and other regulatory authorities worldwide.
[2] X-57 Maxwell Airworthiness Validation Plan, NASA/CR–20220015049, February 1, 2023. https://ntrs.nasa.gov/api/citations/20220015049/downloads/NASA-CR-20220015049.pdf
[3] In 2018, the approach was to use 14 CFR Part 23, Amendment 64, and leverage the ASTM F44 as the MOCs for electrification. However, the Notices of Amendments (NOAs) to address the MOCs began to lag the ASTM F44 standards development. The lessons from the ASTM F44 practices were still relevant, but in 2022,

in response to various concerns from the industry, the FAA pivoted to every certification project coming in as a Special Condition under 14 CFR Part 21.17(b) and allowing the SDOs to develop the necessary standards to be used as MOCs in the PSCP. The term “Powered Lift” was revived to capture some of the projects and let the more traditional projects continue under 14 CFR Part 33 (magniX).

[4] Bendarkar, M. et al., “An Extended MBSE Framework for Regulatory Analysis of Aircraft Architectures.” AIAA AVIATION 2023.

[5] Fields, T., et al., “Applications of an MBSE Regulatory Framework to Electrified Aircraft,” ITEC EATS 2023.

[6] This shows in the first column, 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). In the Hybrid-Electric case, the conventional architecture is 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 case, the number of potential gaps is 163, while 120 are no longer applicable.

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