EWIS Aircraft in Flight Inspection: Certification Aspects and Challenges

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ABSTRACT

Compliance with strict certification requirements constitutes a fundamental part of aircraft design for safe and reliable operation. However, previous regulations fell short of providing specific requirements related to electrical aircraft systems. Two catastrophic accidents in the late 1990s brought aging wiring to the attention of aviation authorities and public, resulting in a new regulatory framework for electrical wiring interconnection systems (EWIS) for FAA Part 25 / EASA CS-25 category aircraft. In this context, EWIS does not only comprise the multitude of electrical aircraft components on board, but represents a change in mindset, implemented by a set of regulations and guidelines for their design, installation, inspection, and maintenance.

Modifying aircraft for flight inspection purposes is a complex undertaking and involves installing additional antennas, consoles, devices, and cables at various locations both inside and outside the (pressurized) cabin. In case of EWIS aircraft, this also includes the selection, routing, and separation of cables as well as the development of instructions for continued airworthiness (ICA) required for supplemental type certificate (STC) approval.

This paper addresses multiple aspects regarding the certification of EWIS aircraft for use in flight inspection and discusses the resulting challenges during the design and modification phase.

INTRODUCTION

Over the last decades, the progress in aircraft technology, the demand for additional functions, and the aim of higher aircraft efficiency have led to a substantial increase in the electrical power installed on commercial airplanes. Modern aircraft architectures increasingly rely on electrically driven systems, resulting in significantly higher electrical generation capacities. As illustrated in Figure 1, the Boeing 787, for example, has an electrical generating capacity of 1.25 MW, which corresponds to the electrical power supply of approximately 1,000 households [11]. Consequently, failures in electrical systems can involve significant amounts of energy, which increases the potential severity of arcing and the associated hazards.

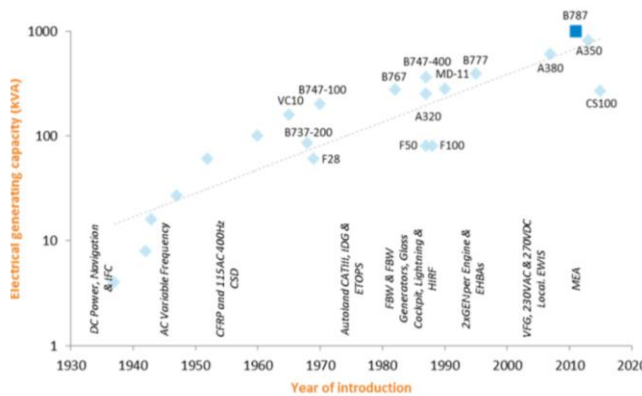


Figure 1: Evolution of Electrical Generating Capacity in Commercial Aircraft [11]

In the early decades of aviation, aircraft maintenance and safety activities mainly focused on mechanical and structural components. Electrical systems, although crucial, were not given the same level of scrutiny in terms of continued airworthiness. Therefore, specific regulatory requirements addressing ICA for electrical systems, including EWIS, were either very limited or not available at all. This situation was mainly based on the assumption that electrical systems were less susceptible to age-related degradation when compared to mechanical components. Although first concerns regarding aircraft wiring safety were raised in the late 1980s, this perception only changed significantly following the two catastrophic accidents involving TWA Flight 800 and Swissair Flight 111 in the late 1990s. These accidents revealed serious weaknesses related to aging aircraft wiring. As a result, they triggered a paradigm shift in the aviation industry's approach to the electrical system, highlighting its safety relevance and potential contribution to severe accidents. [10]

On July 17, 1996, TWA Flight 800 suffered a midair explosion shortly after departure from New York City's John F. Kennedy International Airport on a scheduled flight to Paris. The Boeing 747-100 crashed into the Atlantic Ocean, resulting in the loss of all 230 passengers and crew on board. The subsequent investigation by the United States National Transportation Safety Board (NTSB) concluded that the probable cause was an explosion of flammable fuel vapors in the center wing fuel tank, most likely ignited by a short circuit outside the tank. The investigation identified degraded wire insulation, contamination, and chafing within wiring bundles in the vicinity of the fuel tank. In addition, the wiring system design allowed fault conditions under which electrical energy could be transmitted into the tank, creating a potential ignition source. [12]

Two years later, on September 2, 1998, Swissair Flight 111, a McDonnell Douglas MD-11, crashed into the Atlantic Ocean near Nova Scotia, Canada, killing all 229 occupants. The aircraft was en-route from New York City to Geneva when the crew reported smoke in the cockpit and initiated an emergency diversion. The investigation conducted by the Transportation Safety Board of Canada (TSB) determined that an in-flight fire had originated above the cockpit area. The fire was caused by electrical arcing in the wiring of the in-flight entertainment (IFE) system, which ignited flammable materials in nearby insulation blankets. The rapidly spreading fire led to multiple system failures, including the loss of essential avionics, and ultimately rendered the aircraft uncontrollable. [14]

Both events clearly demonstrated the risks associated with aging and inadequately maintained wiring systems, as well as the importance of considering surrounding materials in the vicinity of electrical installations. In response, aviation authorities and industry initiated considerable efforts to evaluate the condition of aging wiring systems and to develop recommendations for improving continued airworthiness. In 1999, the Federal Aviation Administration (FAA) established the Aging Transport Systems Rulemaking Advisory Committee (ATSRAC), which identified key wiring-related issues such as insulation degradation, physical damage, and contamination that may lead to electrical faults, arcing, and fires. These activities resulted in a comprehensive overhaul of policies related to aircraft electrical systems by the regulatory bodies – namely the FAA and European Union Aviation Safety Agency (EASA) – and aviation industry, where the development of EWIS standards and applicable ICA for FAA Part 25 / EASA CS-25 category aircraft became a focal point. [3] [10]

This paper outlines the EWIS requirements for aircraft certified under Part 25 / CS-25. Considering the plethora of applicable regulations, particular attention is given to selected requirements that are of specific relevance when modifying such aircraft for flight inspection purposes on an STC basis. Furthermore, this paper presents the challenges encountered during the design and modification phases.

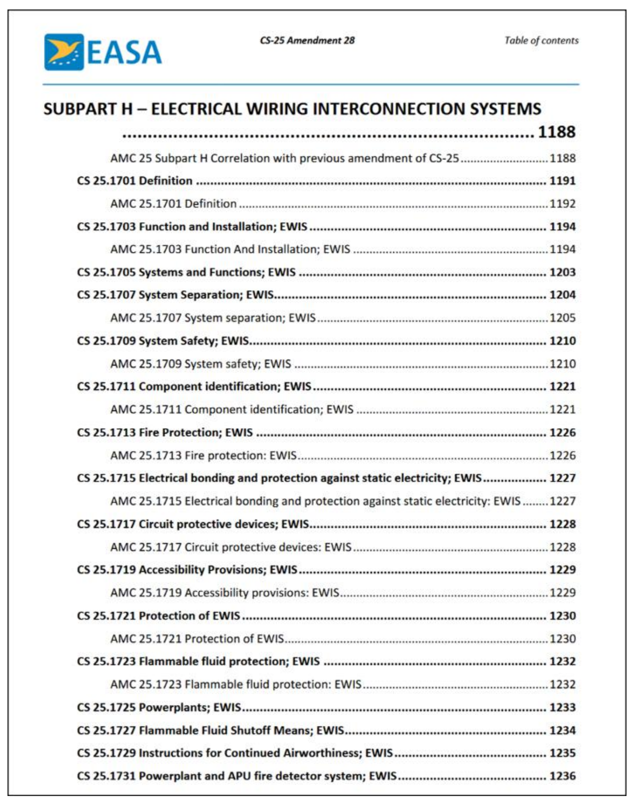
CERTIFICATION ASPECTS

The development of a new aircraft type, as well as the modification of an existing aircraft, is governed by a comprehensive and highly structured regulatory framework. For large, transport category aircraft, the essential airworthiness requirements are defined in FAA Part 25 and EASA CS-25. These certification specifications also form the basis for the approval of aircraft changes and include the applicable requirements for EWIS.

EWIS Regulatory Framework

Following the findings from aging aircraft system reviews and the ATSRAC activities, new EWIS-related regulations were introduced by the FAA with Amendment 123 to Part 25 [9] in 2007 and by EASA with Amendment 5 to CS-25 [6] in 2008. The EWIS certification requirements are defined in Subpart H of Part 25 / CS-25, as shown in Figure 2, while the associated ICA requirements are specified in Appendix H to Part 25 / CS-25 [5]. The development of the EWIS regulatory framework was characterized by close cooperation and a high degree of harmonization between the FAA and EASA. As a result, the corresponding requirements are largely aligned in structure, scope, and technical content [4].

The subsequent discussion focuses primarily on the EASA regulatory requirements, with references to the FAA framework included where appropriate.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SUBPART H – ELECTRICAL WIRING INTERCONNECTION SYSTEMS 1188

Figure 2: EWIS Certification Requirements [5]

Subpart H establishes fundamental safety standards for the design, installation, separation, and protection of electrical wiring and associated components, including considerations related to fire prevention and damage tolerance. Appendix H complements these requirements by addressing the maintenance and inspection aspects necessary to ensure the integrity and reliability of aircraft wiring systems throughout the aircraft's operational life. Appendix H, in particular sections H25.4 and H25.5, requires applicants to develop dedicated EWIS ICA. These instructions include defined inspection tasks and intervals, procedures to assess wiring condition and integrity, and measures to prevent or mitigate wiring degradation. Together, these elements form the basis for the EWIS maintenance concept, commonly referred to as the wiring maintenance program (WMP). [4] [5]

Within the EASA regulatory framework, compliance with the CS-25 EWIS requirements is supported, amongst others, by a set of acceptable means of compliance (AMC). Relevant documents include the AMC to CS-25 [5] and sections 21, 22, and 23 of AMC 20 [3]. The AMC to CS-25 provides guidance for the certification of EWIS and supports both applicants and authorities in demonstrating compliance with the applicable certification requirements. AMC 20-21 focuses on enhancing EWIS maintenance programs through zonal analysis, AMC 20-22 defines training programs for personnel involved in EWIS-related activities, and AMC 20-23 establishes standards for electrical wiring practices documentation. Moreover, EWIS-specific certification review items (CRI) and special conditions (SC), such as CRI H-01 / SC H-01 [2], may be applied to address aircraft- or modification-specific aspects that are not fully covered by the baseline requirements.

Additional documentation is provided by the FAA in the form of advisory circulars (AC), such as AC 25.1701-1 [7] and AC 25.27A [8]. While AC 25.1701-1 includes more detailed guidance than the AMC to CS-25, AC 25.27A addresses continued airworthiness aspects and describes the process and expectations for the development of EWIS ICA.

The EWIS regulations are not limited to new aircraft certification programs. They were also intended to be applicable to in-service aircraft and are therefore relevant for minor changes, major changes, and STC projects. Under EASA regulations, the applicable certification basis for a design change or repair is determined in accordance with Part-21, considering the aircraft's type certificate data sheet (TCDS) and the classification of the proposed change. [4]

Figure 3 depicts the applicability of the EWIS requirements for STC-based aircraft modifications for flight inspection purposes. If the aircraft's certification basis in the TCDS is CS-25 Amendment 5 or higher, the EWIS requirements of CS-25 Subpart H apply and the impact of the proposed modification on the relevant EWIS paragraphs, including the associated ICA defined in Appendix H, must be assessed. [4]

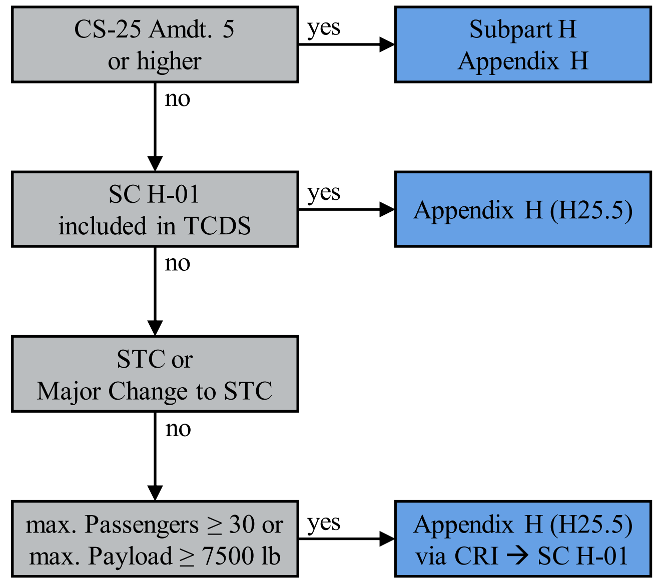

Figure 3: Applicability of EWIS Regulations for STC-based Aircraft Modifications (based on [4])

For aircraft certified to a CS-25 amendment level below Amendment 5, the applicability of EWIS ICA requirements depends on the inclusion of the special condition SC H-01 [2] in the TCDS. Where SC H-01 is not already part of the certification basis, EASA will introduce this special condition via a CRI for STC projects and major changes to STCs, provided the affected aircraft meets the applicable passenger or payload thresholds. This approach ensures consistent application of EWIS ICA requirements for significant modifications of in-service aircraft under EASA oversight. Applicants for an STC are not required to voluntarily elect full compliance with CS-25 Subpart H unless mandated by the applicable certification basis or special conditions. [4]

In the following sections, selected EWIS requirements of CS-25 Subpart H [5] are discussed in more detail due to their particular relevance for the design, certification, and continued airworthiness of STC-based aircraft modifications. The focus is placed on the following paragraphs:

- CS 25.1701 – Definition
- CS 25.1707 – System Separation
- CS 25.1709 – System Safety
- CS 25.1729 – Instructions for Continued Airworthiness

CS 25.1701 – Definition

CS 25.1701 defines the scope of EWIS for applying the EWIS requirements of CS-25 Subpart H and associated EWIS-related provisions. EWIS is defined as any wire, wiring device, or combination thereof, including termination devices, installed in any area of the aircraft for the purpose of transmitting electrical energy, including data and signals, between two or more intended termination points.

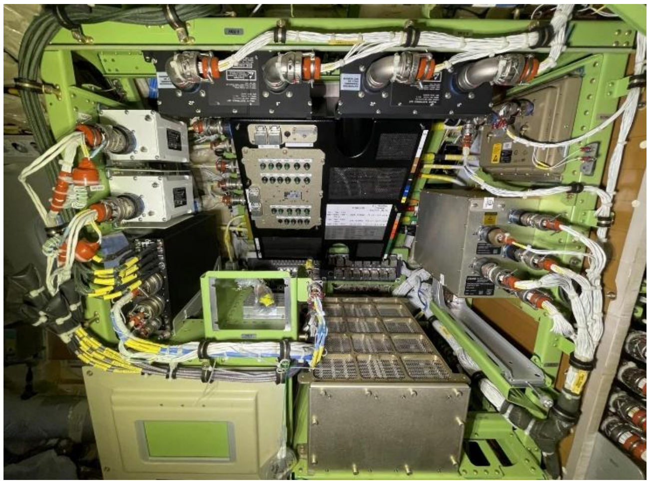

Figure 4: EWIS and Non-EWIS Components located inside an Electronic Rack

As shown in Figure 4, this definition covers a wide range of wiring components, such as wires and cables, connectors and connector accessories, splices, grounding and bonding devices, shielding and braiding, protective materials, clamps, cable ties, labels, and pressure seals. In addition, EWIS components located within shelves, panels, racks, junction boxes, distribution panels, and equipment back planes are considered part of the aircraft EWIS, as such installations are typically aircraft-specific and maintained and modified as part of the aircraft wiring system.

The component types listed in CS 25.1701 are intended to define the scope of EWIS but do not represent a closed list. Any component that supports the transmission of electrical energy and meets the EWIS definition is subject to the EWIS regulatory requirements, regardless of whether it is explicitly enumerated.

Certain components are explicitly excluded from the EWIS definition. These exclusions comprise wiring located inside electrical or avionic equipment that is environmentally qualified to acceptable standards, such as RTCA DO-160G [13] / EUROCAE ED-14G [1], portable electronic devices (PED) that are not part of the aircraft type design, and fibre-optic systems. For qualified equipment, the environmental robustness demonstrated by testing justifies exclusion from EWIS-specific requirements, as maintenance and repair are typically performed by the equipment manufacturer or specialized repair facilities rather than as part of aircraft wiring maintenance. [5]

CS 25.1707 – System Separation

The continuing safe operation of an aircraft depends on the reliable and safe transfer of electrical energy by the EWIS. Consequently, adequate separation of wiring systems is required to prevent failures, damage, or environmental effects in one system from adversely affecting other systems.

CS 25.1707 requires that each EWIS must be designed and installed with adequate physical separation from other EWIS and from other aircraft systems so that an EWIS component failure will not create a hazardous condition. This separation must be achieved either by sufficient physical distance or by the use of protective barriers, such as sleeves, tubes, or conduits. In general, physical distance is the preferred means of separation, as barriers themselves can become a source of EWIS component damage. Where barriers are used, their design and installation must therefore be carefully assessed to ensure that they do not introduce new failure mechanisms.

To demonstrate that a given EWIS failure will not result in a hazardous condition, applicants are required to perform a qualitative design assessment of the installed EWIS. This assessment is based on reasonable engineering and manufacturing judgment and should take into account relevant service history, where available.

The primary purpose of system separation is to mitigate hazardous effects resulting from mechanical and electrical interference to an acceptable level. Mechanical interference may arise when EWIS is installed in close proximity to other components without sufficient separation. Typical examples include chafing between electrical wiring and structure, piping, or other wire bundles, as well as jamming or restriction of movement where wiring is routed near movable components. These interactions can lead to degradation of insulation, conductor damage, failure of wire support elements, or secondary effects such as fluid leakage from adjacent systems. Electrical interference may result from electrical arcing and electromagnetic interference (EMI), such as conducted or radiated emissions, coupling between adjacent wiring or cable bundles, malfunctioning of electrically powered equipment, or parasitic currents within the electrical distribution and grounding systems. Accordingly, CS 25.1707 mandates adequate separation of EWIS from fuel, hydraulic, oxygen, water / waste, and flight or mechanical control systems, from heated equipment, ducts, and lines, as well as from heavy current-carrying cables. In addition, EWIS associated with independent power sources and redundant systems must be physically separated and electrically isolated to prevent fault propagation and preserve system independence.

Determining the appropriate amount of physical separation distance is an essential task. However, as system designs, aircraft configurations, and installation practices differ between manufacturers, CS 25.1707 does not define specific separation distances. Instead, adequate separation is established on a case-by-case assessment, considering factors such as electrical characteristics, amount of power, severity of failure conditions, installation design features, probable variations in the installation, intended operating environment, and susceptibility to EMI, high-intensity radiated fields (HIRF) or induced lightning effects. Typically, specific values are provided in the aircraft manufacturer's standard wiring practices manual (SWPM). [5]

CS 25.1709 – System Safety

CS 25.1709 addresses system safety from EWIS perspective and requires that EWIS must be designed and installed such that failure conditions do not compromise aircraft safety. In line with the safety objectives defined in CS 25.1309 (equipment, systems and installations), the regulation requires that each catastrophic EWIS failure condition must be extremely improbable and not result from a single failure, and that each hazardous EWIS failure condition must be extremely remote.

Although the wording of CS 25.1709 closely follows that of CS 25.1309, its application differs in scope and intent. Compliance with CS 25.1709 requires a thorough and structured safety analysis of the aircraft wiring and its associated components, rather than a conventional system-level evaluation. The safety assessment is primarily qualitative and applies the fail-safe design concepts of CS 25.1309, assuming that single EWIS failures, such as chafing or arcing, can occur regardless of probability.

While system safety assessments performed under CS 25.1309 typically evaluate the effects of failures at the system level, CS 25.1709 extends the analysis to the aircraft level, as illustrated in Figure 5. In addition to functional failures, this assessment must explicitly address physical failures of EWIS, such as wire insulation breakdown, arcing events, or wire bundle damage, and evaluate their potential to affect other systems and aircraft structures.

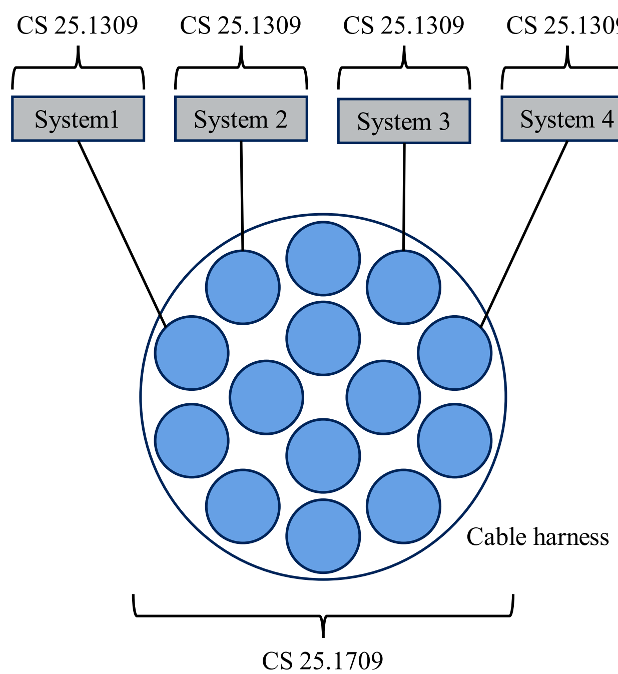

Figure 5: System-Level (CS 25.1309) and Aircraft-Level (CS 25.1709) Safety Assessment

A key objective of CS 25.1709 is to address limitations observed in traditional system safety analyses, where wiring associated with non-essential systems has sometimes been excluded. CS 25.1709 explicitly requires that all EWIS installations must be considered, regardless of whether the associated system function is classified as required or non-required. Failures of wiring associated with systems such as IFE may still have severe effects on other aircraft systems, for example through arcing events damaging flight control cables or through wire bundle failures leading to fire or structural damage, as highlighted by the Swissair Flight 111 accident investigation.

The integrated nature of EWIS and the potential severity of wiring failures demand a more comprehensive assessment approach than that traditionally applied under CS 25.1309. EWIS failures must therefore be analyzed to determine their potential effects on the continued safe operation of the aircraft as a whole, including interactions between adjacent wires, bundles, and systems.

A suitable starting point for demonstrating compliance with CS 25.1709 is the aircraft-level functional hazard analysis (FHA) developed in accordance with CS 25.1309. The FHA provides the basis for identifying hazardous and catastrophic failure conditions, which are then used to assess both the functional and physical effects of EWIS failures. [5]

CS 25.1729 – Instructions for Continued Airworthiness

CS 25.1729 requires the applicant to prepare ICA applicable to EWIS in accordance with CS 25.1529 (instructions for continued airworthiness) and Appendix H, paragraphs H25.4 and H25.5. The ICA constitute a critical element of the aircraft maintenance program, as they ensure that EWIS installations are maintained in a safe and airworthy condition throughout the operational life of the aircraft. They provide maintenance personnel with the procedures, methods, and practices necessary to safely inspect, maintain, clean, repair, and restore wiring installations. Their primary objective is to prevent EWIS degradation and failures, and to minimize the accumulation of combustible material that could otherwise lead to fire hazards, malfunctions, or other unsafe conditions.

In accordance with Appendix H, the ICA must include a clearly identifiable airworthiness limitations section (ALS). This section contains any mandatory replacement times applicable to EWIS components as defined in CS 25.1701, where such replacement is necessary to maintain continued airworthiness. While EWIS components are generally selected for the service life of the aircraft, any component requiring periodic replacement must be explicitly identified together with its approved replacement interval.

Appendix H specifies that EWIS-specific maintenance and inspection tasks are to be developed using the enhanced zonal analysis procedure (EZAP). The EZAP provides a systematic process to assess EWIS installations within the aircraft's zoning structure, considering factors such as system criticality, proximity to other systems, and the presence of combustible materials. Based on this assessment, targeted inspection and maintenance tasks are defined to reduce the likelihood of ignition sources and the accumulation of combustible material.

From the EZAP results, appropriate inspection task types and intervals are established for each affected aircraft zone. These may include stand-alone or zonal general visual inspections (GVI) or detailed inspections (DET), depending on the assessed risk and criticality. As a general principle, zones containing more critical systems or EWIS installations with higher exposure require more detailed inspection tasks.

For STC projects, applicants typically do not have access to the type certificate (TC) holder's original EZAP or corresponding documentation. In such cases, a structured, flowchart-based approach, as depicted in Figure 6, is applied to determine whether existing EWIS ICA remain adequate or whether new EWIS ICA must be introduced for specific affected zones. This ensures that modifications do not invalidate previously approved maintenance assumptions and that the continued EWIS airworthiness is maintained.

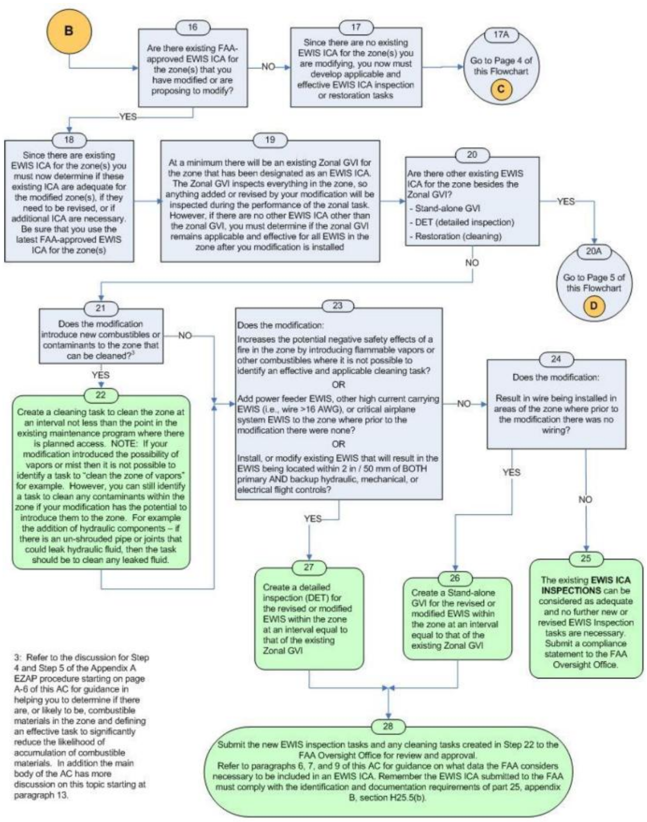

Figure 6: EWIS ICA Decision and Development Flowchart for Non-TC Holders [4]

The ICA must also include acceptable wiring maintenance practices, typically documented in a SWPM, as well as EWIS separation requirements established under CS 25.1707. [5]

CHALLENGES

While the majority of flight inspection aircraft is certified under Part 23 / CS-23, some flight inspection providers prefer to use larger aircraft, based on their specific requirements. For aircraft certified under Part 25 / CS-25, EWIS requirements may become applicable. Consequently, flight inspection modifications must be developed with careful consideration of EWIS-related design and certification aspects.

EWIS applicability cannot be determined solely by aircraft size, age, or market segment, but depends on the certification basis defined in the applicable TCDS. This is illustrated by Table 1, which shows that even aircraft of similar size and entry-into-service date may differ with respect to EWIS applicability.

Table 1: EWIS Applicability of Typical Types of Flight Inspection Aircraft

Part 23 / CS-23: Non-EWIS Aircraft
Beechcraft King Air 200 / 250 / 260
Beechcraft King Air 300 / 350 / 360
Cessna 408: SkyCourier
Cessna Citation 560XL: Excel / XLS / XLS+ / Ascend
Embraer EMB-505: Phenom 300
Partenavia AP-68TP-600: Viator
Piaggio P.180: Avanti / Avanti II
Pilatus PC-24
Part 25 / CS-25: Non-EWIS Aircraft
Cessna 680: Citation Sovereign / Sovereign+
Cessna 680A: Citation Latitude
Gulfstream GVI: G650 / G650ER
Part 25 / CS-25: EWIS Aircraft
ATR 42 / 72
Cessna Model 700: Citation Longitude
Embraer EMB-545: Legacy 450 / Praetor 500
Embraer EMB-550: Legacy 500 / Praetor 600
Gulfstream GVIII: G700

Modern automatic flight inspection systems (AFIS) are deeply integrated with the aircraft's primary systems, e.g. for providing precise flight guidance or recording data. This requires specific insight into the various platforms and a specialized design for one airframe.

In the past, many certification aspects of flight inspection modifications were addressed using the 'no safety, no benefit' principle. Under this approach, AFIS installations were treated as non-essential systems, comparable to passenger convenience systems such as IFE. The underlying assumption was that failures of the AFIS would neither jeopardize aircraft safety nor impose operational limitations.

However, with respect to the EWIS requirements, this approach is no longer viable. Even if the AFIS itself does not perform safety-critical functions, the associated wiring installations can introduce safety risks, for example through mechanical interference, electrical arcing, or unintended interactions with safety-critical wiring. Since flight inspection systems typically consist of numerous components distributed throughout the aircraft, extensive additional wiring and interconnections are required. Consequently, all newly installed wiring must be designed, installed, and maintained in compliance with EWIS requirements.

Meeting these requirements has a direct impact on the entire modification process. EWIS considerations must be taken into account from the very beginning of a project, as they affect electrical and mechanical design, installation activities, tests and inspections, as well as certification and maintenance documentation. Compliance requires close coordination between electrical and mechanical design disciplines, including early definition of cable routing, system separation, accessibility, and inspection concepts. Due to this increased design complexity, flight inspection modifications must be supported by dedicated design and configuration tools capable of tracking EWIS-related requirements and their implications for both the electrical and mechanical design. Such tools must integrate seamlessly with the respective electrical and mechanical design environments in order to ensure a consistent, traceable, and efficient workflow throughout the project. This level of coordination demands qualified personnel with specific EWIS expertise and leads to a significantly higher level of engineering effort compared to modifications on non-EWIS aircraft.

The impact of EWIS requirements is further intensified by practical project constraints. Flight inspection modifications are often developed using an iterative approach, particularly when early access to the aircraft is limited. In addition, STC applicants typically have no or only limited access to detailed design data of the TC holder or aircraft manufacturer, including original EWIS or EZAP analyses, separation concepts, or maintenance assumptions. This lack of detailed baseline information increases the effort required to define compliant wiring routes, inspection concepts, and ICA content, and often necessitates conservative design choices and additional validation activities. At the same time, EWIS compliance typically requires an early design freeze to support system separation concepts and the development of ICA. Deviations between the theoretical design and the installed configuration may therefore require late changes to cable routing or equipment locations. Under EWIS constraints, such changes can trigger extensive re-engineering activities, additional certification steps, and delays.

These challenges are particularly pronounced for transport category business jets. In corporate aviation, passenger comfort and efficient use of cabin space are prioritized, resulting in very limited installation space for additional equipment and wiring. High-density areas such as avionic bays, underfloor compartments, bulkheads, and the flight deck are already congested, and EWIS separation and accessibility requirements further restrict available routing options. At the same time, EWIS inspection concepts require wiring to remain accessible, which can conflict with interior design, layout constraints, and cable protection.

In cases where ideal separation cannot be fully achieved, dedicated safety assessments at aircraft zone level become necessary. Such assessments must consider not only the newly introduced wiring but also existing installations within the same zone. This integrated evaluation is often complex and time-consuming and represents an additional challenge in the certification of EWIS-compliant flight inspection modifications.

SUMMARY & CONCLUSION

Previous certification regulations did not provide a comprehensive framework to address wiring-related hazards at aircraft level. With the introduction of a dedicated regulatory framework for EWIS by FAA and EASA, wiring and associated components are no longer viewed merely as individual electrical elements governed by additional rules. Instead, EWIS represents a fundamental change in mindset, treating wiring as a ‘system’ that enables and interconnects multiple aircraft functions rather than serving a single, isolated function.

In summary, these aspects demonstrate that the modification of EWIS-applicable aircraft for flight inspection purposes entails a substantially higher level of complexity and effort than comparable modifications on non-EWIS aircraft. The need for early and detailed design decisions, increased coordination across disciplines, extended analysis and documentation activities, and reliance on specialized expertise results in longer project timelines and significantly increased organizational and engineering resources. These implications must be considered from the outset when planning and executing flight inspection modifications on EWIS aircraft.

DISCLOSURE

Microsoft Copilot was used as AI-based language tool solely to improve readability and language quality. All technical content, interpretations, and conclusions are the responsibility of the author.

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