Abstract — Recent trends in aircraft system architecture have resulted in increasing use of Electrical Systems to perform functions previously performed by Mechanical, Hydraulic or Pneumatic Systems. The principle advantages to this approach being reduced weight and installation space requirements, improved reliability and system self-diagnostic functions and often simplified flight-line service and maintenance requirements. This has led to a significant increase in the quantity of electrical wiring and increasing levels of Design Assurance Levels (DAL) assigned to Electrical Systems. An additional consequence is the increasing demand for distributed electrical power. Further complexity is introduced by the use of composite structure in which the current return, fault current paths and equipotential ground reference plane for electrical systems inherent in metallic structure, must be specifically provisioned for composites. These added complexities require new considerations for system redundancy and reliability, inspectability and maintainability, the latter contributing to the Instructions for Continued Airworthiness.

The Federal Aviation Administration (FAA) [1] and European Aviation Safety Agency (EASA) [2] have produced regulations applicable to the wiring for Transport Category Aircraft for example EASA CS-25 Subpart H [2]. These regulations now introduce the concept that the wiring is not just an interconnection means, but it is a system in its own right known as the Electrical Wiring Interconnection System (EWIS). Consequently there is the need to develop a new approach to regulatory compliance, beyond the conventional integration activity. This paper highlights the general approach to the design and certification planning of “A More Electric Aircraft” adopted on a recent Business Aircraft project.

Keywords: EWIS, FAA Part 25, EASA CS-25 Subpart H, requirements, compliance, composite vs. metallic structures

I. INTRODUCTION

The advent of the new EWIS regulations and the increasing number of essential electrical systems has resulted in two situations for the Airframe Manufacturer. These can be broadly described as follows. For existing non-essential electrical systems it is necessary to ensure the EWIS installation itself does not pose a safety hazard to the aircraft during its service life. This has led to increased emphasis on reliability, inspectability and maintainability of the design leading to specific instructions for continued airworthiness. For the increasing number of essential electrical systems emphasis must be placed on system segregation for damage tolerance, system separation for Electromagnetic Compatibility (EMC) and protection against environmental conditions and common cause Electromagnetic threats such as High Intensity Radiated Field (HIRF) and Lightning. Deriving system design requirements to achieve all of these aspects is one of the initial steps required to achieving a certifiable design, but one that requires significant investment in resources. Following from the requirement definition is the assignment of ownership for each requirement and the validation phase where the set of design requirements is determined to be complete and appropriate. This will be discussed in more detail within this paper. Ultimately the requirement verification, which due to the nature of EWIS tends to be a “qualitative” rather than “quantitative” approach to compliance, is performed relying heavily on implementation of standard practices, standard components, design tools, methods and process control. Regular reviews are preformed at each stage of the development and certification program which encompass manufacturing and continuing through entry into service and the evaluation of customer service reports. Design solutions are required to consider the effects on aircraft weight, cost, reliability, manufacturability and maintainability. Success ultimately demands close co-operation between not only the different System and Wiring Design Engineers, but also Structures, Aircraft Configuration, Airworthiness, Manufacturing and Maintainability and Support departments.

II. EWIS DESIGN STANDARD PRACTICE

Unlike the larger airframe manufactures, the smaller airframe companies have relatively limited resources available to document individual methods and practices. The process adopted at Piaggio Aero Industries (PAI) has been to compile a single design manual that documents the standard practices to be adopted for EWIS Design and Installation. This manual forms part of the Part 21[3], [4] Design Organization Handbook. The manual is intended as the primary design reference and provides information on:

- Aircraft Environmental Zoning
- Approved Materials and Components
- Approved tooling
- EWIS Component and Wire Identification
- Wiring Assembly
- EWIS Installation
• Specific System Routing
• Electrical Devices included in the EWIS
• General Reference material such as de-rating curves
• Maintenance practices

Where appropriate the standard practices are translated into design rules that are embedded within the CAE (Computer Aided Engineering) design tools, used for Wiring Diagrams, Harnesses drawings and Harnesses installation into the Digital Mock-Up (DMU) and linked to the Product Lifecycle Management (PLM) tool. Particular examples are rules applicable to harness routing and segregation as discussed later. A key aspect for the successful implementation of the standard practices is the alignment with production processes and use of standard components. It should be noted that the design manual is a living document that is updated as new methods, materials and components become available. It is imperative for the manufacturing department to periodically review the design manual and highlight areas where implementation of a particular design requirement can be tailored to facilitate ease of manufacturing.

A. Design Tools

The increased electrical system complexity of the MEA requires the use of design tools to automate and document the design where practical. This includes encompassing the system Interface Control Document (ICD) or Installation Manual requirements, implementation of the Standard Design Practices, optimize equipment installation and EWIS routing and maintain overall configuration control of the design.

The principle tools utilized are the Wiring CAE tool used to:
• Manage the wire databases including the system interface requirements
• Produce the principle interconnect block diagrams
• Produce the wiring diagrams by ATA chapter
• Produce the wire lists and bill of materials for the harness manufacture
• Manage the electrical harness design by drawing on the interconnect information in the Electrical Data Base

and the DMU CAE tool used to:
• Manage the geometrical harness design through a solid representation of the harness in the DMU
• Provide installation routing within the airframe and clash resolution
• Produce the EWIS installation drawings
• Produce the bill of materials for the EWIS installation components within the airframe
• Manage the Form Board layout using a process of flattening the harness two dimensionally to facilitate manufacturing

The design tools contain libraries of approved components that are selected for the harness design and installation. Installation rules are also programmed into the CAE tool to control the routing of the EWIS. As an example EWIS support design rules will define the number of clamps and clamp spacing and location required and assure the minimum stand-off distances to equipment, structure and other harness including the case where a single support failure has occurred.

B. System Segregation and EMC Separation

The MEA usually has electrical systems providing essential functions. The system architecture provides redundancy in the case of a partial system failure so that the critical and essential functions of the systems are maintained. When designing the EWIS installation it is necessary to consider the system architecture to preserve the level of redundancy under foreseen failure conditions identified in the aircraft Functional Hazard Analysis, System Safety Analysis and Particular Risk Analysis. Considerations include risks such as engine rotor burst, thrown tyre tread, wheel rim release, localized structural failure, fire to name but a few. The design must provide sufficient segregation between redundant channels of a system or a system and its back-up system to ensure that no single event or likely combinations of events result in the total loss of a critical or essential function. The EWIS design and installation must take into account each of these risks to ensure that:
• Multi-redundant Channels of an essential system separated into separate harnesses.
• Harnesses carrying system multi-redundant channels are not routed together through the same part of the aircraft. Typically a Left / Right side of the aircraft segregation is required
• Systems providing back-up functions to other systems are not routed in the same harness or location in the aircraft.
• Where physical segregation distances cannot be maintained, additional protection (sometimes a physical barrier) is provided against the foreseen threats applicable to the zone.

EMC separation classifies individual wire types according to their susceptibility or emissive characteristics irrespective of the system they are associated. The EMC classifications are separated into different bundles with a defined physical separation distance between them to eliminate interference between circuits. The separation distance takes into account the signal characteristics and also may also consider the length of the wire runs, longer parallel runs having greater potential for electromagnetic coupling. Space constraints at certain “choke points” in the aircraft may prevent the desired separation distances from being achieved in which case the length over which the separation is compromised must be considered and additional electromagnetic protection in the form of shielding added if appropriate.
III. SPECIFIC INSTALLATION REQUIREMENTS

Some EWIS installations have special requirements which are attributed to the level of protection provided by the structure, particular environmental conditions or particular system safety considerations. To illustrate an example consider the routing of the EWIS through a Carbon Fiber Composite (CFC) part of the airframe. Special provisions may be required to route the EWIS in metallic raceways to provide Indirect Effects of Lightning (IEL) protection by reducing the induced transient levels attributable to the resistive CFC structure. These raceways may also serve multiple purposes as the electrical system current return path and fault current paths for local electrical loads. According to the 25.1701 regulation [1], [2] these raceways and their interconnections are defined as being part of the EWIS. Moreover the resistive CFC structure is intolerant of large currents which can cause local heating, loss of structural integrity or even fire. It is therefore necessary to provide isolation between the current return and fault current paths to prevent the injection of large currents into the CFC structure under normal or fault conditions. System segregation usually requires the use of multiple raceways. Each raceway must be sized so as not to exceed the maximum occupancy rules for optimum IEL protection. Interconnections between raceway segments and metallic structure must be of low impedance requiring the minimisation of the connecting path’s self-inductance and providing effective electrical bonding at the connection points. The raceway must be secured itself to the primary airframe structure as well as providing attachment points for the harnesses routed within. The overall design of the raceways system must be optimized to reduce weight and parts count without sacrificing performance. Equally it must also be easily manufactured, facilitate inspection and economically maintainable.

IV. DISTRIBUTED ELECTRICAL POWER

An obvious consequence of the design of the MEA is the increasing demand for electrical power. Aside from the increased sizing of generators and batteries the MEA requires electrical power to distributed to various parts of the aircraft whilst minimising losses due to IR heating and Voltage drop. Modern Electrical Power Distribution systems also offer architectures that can combine the functions of conventional circuit breakers with system logic control and monitoring for some types of systems. Systems that particularly suite this approach are those which have high current demand, but relatively simple control logic, examples being windshield or Pitot de-icing. From the EWIS perspective the consequences are to design and install the power distribution wiring and ensure that the circuit protection devices contained in the Electronic Circuit Breaker Units (ECBU) are adequate to protect the wiring under fault conditions. In the case of routing in composite structural locations this must also consider the current return and fault current paths.

Selection of the power distribution system architecture should require an EWIS trade study to determine the weight, space requirement, and power loss impact of the various sized power feeders that may form a significant portion of the EWIS.

V. DESIGNING FOR MAINTAINABILITY

For many older aircraft designs little attention was given to how the electrical wiring was to be maintained in service, the wiring being considered to have the life of the airframe itself. In today’s certification environment it is necessary to identify foreseeable fault conditions, produce fault tolerant designs but still allow provision for inspection and maintenance operations in service. Key aspects include:

- Providing easy access to wire harnesses without major disassembly or equipment removal
- Visual inspection without recourse to specialist equipment or methods
- Limiting the size of individual harnesses to allow easier inspection of individual wires making up the harness
- Limiting the use of conduit that enclose wire bundles
- Ensuring EWIS components are qualified for the environmental conditions they will experience in service.
- Selecting materials and components to minimise environmental and galvanic corrosion.
- Installing EWIS in a manner that prevents accidental damage during foreseeable service use or aircraft maintenance activity

It is required to provide Instructions for Continuing Airworthiness (ICA) that include the inspection intervals, the inspection techniques to be used, any service activity required such as cleaning and the replacement of any specified life components within the EWIS. The ICA are produced under the overall aircraft Maintenance Steering Group 3 (MSG3) activity and forms part of the Zonal Analysis Process (ZAP) with additional EWIS specific requirements defined under Enhanced Zonal Analysis Process (EZAP). The EZAP identifies the physical and environmental conditions contained in each zone of an aircraft, analyses their effects on electrical wiring and assesses the possibilities for flame and fire through damage to and contamination of the EWIS. From such an analysis, maintenance tasks are developed to prevent ignition sources and to minimize the possibilities for combustion by minimizing the accumulation of combustible materials. These tasks are subject to Maintenance Review Board (MRB) activity and ultimately promulgated as ICA.
VI. EWIS CERTIFICATION

There is little that can be empirically measured from the design of the EWIS thus certification of the EWIS as a system is based on Qualitative rather than Quantitative methods. The verification of the EWIS requirements is a multi-faceted approach relying on having well documented standard practices with the process control to implement them. Evidence is provided by internal reviews and audit trails to demonstrate the design processes are followed.

Design requirement must consider not only the EWIS regulations but also the Supplier Interface Requirements, Aircraft Functional Hazard Analysis and the System Safety Analysis and Particular Risk Analysis. Requirements are assigned to individuals but are tracked via a requirements management tool. At each stage of design cycle from Aircraft, through System to Equipment Level the set of derived design requirements is validated by review to ensure that they are correct and address all aspects of the design. The EZAP is instrumental in not only defining the maintenance requirements but also highlighting the particular threats posed to the EWIS in a particular zone allowing appropriate selection of materials, components and levels of protection.

The design tools and databases are a key part of maintaining configuration control and showing adherence to the standard practices. An Engineering Control Board (ECB) is established to review, disposition and record exceptions to the standard methods on a case-by-case basis.

Finally the EWIS design groups provide input to the MRB resulting in production the ICA and monitoring their effectiveness during service.

VII. CONCLUSION

The trend for the increasing use of electrical systems in place of traditional mechanical, hydraulic and pneumatic systems on MEA offers certain advantages such as weight reduction, reliability and reduced flight line servicing. The advantages must be considered against the requirement for increased design rigor and in-service maintenance of the EWIS brought about by its function within essential systems and recent regulatory changes. The advent of the MEA has also coincided with the increased use of composite structure that brings additional requirements to the EWIS design, installation and maintainability.

It must be considered that electrical systems are potentially vulnerable to electromagnetic threats. The DAL and the levels of exposure of the system to a particular threat will drive the level of protection required.

The complexity of the MEA requires the use of specialist design tools that not only perform the design function, but also support certification through the use of standard materials, components, methods and maintaining configuration control.

Ultimately a highly coordinated design approach using the Integrated Product Teams encompassing skills from many systems, structures, airworthiness and manufacturing departments is a key aspect to an efficient design and certification program.

REFERENCES

[5] Air Transport Association (ATA) iSpec 2200