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# DESIGN FOR MANUFACTURING AND ASSEMBLY METHODOLOGY APPLIED TO AIRCRAFTS DESIGN AND MANUFACTURING

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***Abstract.*** *This paper presents a guideline which uses the concepts of DFMA (Design for Manufacturing and Assembly) methodology for specific application on aircrafts design and manufacturing. The main goal of the guideline is to guide the engineers during the aircraft development phases, such that a better aircraft design is achieved. The guideline provides a better evaluation of manufacturing processes, assembly, maintenance, capability and human factors (ergonomics). It is expected to improve the manufacturing and simplify the assembly to become easier the manufacturing of parts that will make the aircraft final assembly with low costs, high quality and the best optimized condition. A case study is showed to testify the advantages and benefits achieved when the proposed tool is used.*

***Keywords:*** *DFMA, Aircraft, Design, Manufacturing, Product Integrated Development.*

## 1. INTRODUCTION

The non effective application of DFMA methodology during the aircraft development can contribute to the increasing of production times, quality problems and high costs on final end item product. Many points need to be checked during the product design phase in order to get a design with characteristics of easy manufacturing and assembly (Barbosa, 2007).

The DFMA objectives are to develop a product that meets all the functional needs and is easy to manufacture and assembly. DFMA methodology can help the integration of product development departments (Engineering and Design) and production areas (Manufacturing and Assembly) allowing preliminary actions during the development phase to avoid problems at manufacturing stages (Bayoumi, 2000).

This research work aims to help the increase of aircrafts manufacturers competitiveness through the application of DFMA methodology tailored for this kind of industry.

## 2. THEORETICAL BACKGROUNDS

### 2.1 DFMA methodology

DFMA is a technique used during the product development and improvement that aims to further an easy manufacturing and assembly costs reduction (Boothroyd, *et al,* 1994).

Therefore, when creating a new product, DFMA should be applied at an early stage of the project design to identify the needs that the product must meet.

The methodology bases on part reduction, that is, a decrease of the number of parts per product and the number of part types (reaching a minimum number of components). The use of DFMA methodology provide many other benefits to the product such as quality improvement, parts numbers reduction, simplicity of assembly processes, standardizing, capability and manufacturing costs reduction (Corbett, *et al,* 1991).

Another method developed by companies and researchers to support the designers and engineers to evaluate the impact of the suggested solutions is the DFX (Design for Excellence).

According to Bralla (1996), the “X” represents any other factor referring as a problem to be solved, such as quality, production, maintenance, environment, ergonomic, etc.

### 2.2 Concurrent Engineering

It can be confirmed by studies and production evidences that DFMA reaches better results when associated to the known methodologies, for example the simultaneous engineering. The use’s objective of simultaneous engineering during the product development is to assure the people integration in work groups, composed by expert persons of different areas. This integrated approach allows all engineers, the opportunity to work together simultaneously, so that the resulting designs "would represent an interconnected web of decisions" (Nevins & Whitney, 1989).
Thus, engineers must analyze several important points, not only the product but also for requirements that aim to get a product with low cost, assuring the best combination between technical specifications.

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### 2.3 Product Integrated Development

Product developments applied to aeronautics industries is in evolution and continuous improvements. It’s for getting and sustaining the attractiveness and competitiveness of manufacturers. Variables such as: time, quality, cost, environment and logistics are always considered in each decision taken (Azamatov, *et al*, 2011).

## 3. GUIDELINE FOR AICRAFT DESIGN AIMED TO MANUFACTURING AND ASSEMBLY

### 3.1 Introduction

According to author's background and experience by visits and benchmarking at aircraft manufacturers have show that the product developments usually have been made without a carefully analyze for manufacturing and assembly and its related processes. Those evidences have been obtained from assembly lines, maintenance and support personnel at shops and airports, service bulletins application, revisions on delivered aircrafts and also information obtained from technical reports and marketing.

Analyses should have been done before the manufacturing of the first aircraft on production to assure that the design is mature and really according to the fabrication requirements. It could avoid the increasing of redesign time for needs of future revisions on design and become the final product more expensive.

So, because the points described above is recommended the effective use of development resources and DFMA tools in conjunction with manufacturing engineering department experiences.

### 3.2 Proposal of DFMA Guideline for Engineers

To make easier the application of DFMA rules and concepts on aeronautics industries, it has been developed a simple tool in form of table’s verification. Those tables contain the most important points to be analyzed and exploited during the product development. This tool serves as a guideline during the product development and it can also be used as a training tool for new employees and those who just need the basics on the DFMA methodology.

This DFMA guideline consists of a series of 12 tables, with the verifications to be followed and used as a guide to aid engineers in designing and manufacturing phases of product.

Figure 1 shows the structure of check list requirements and its division of the specific topics to be considered in the design and detailing of the product.

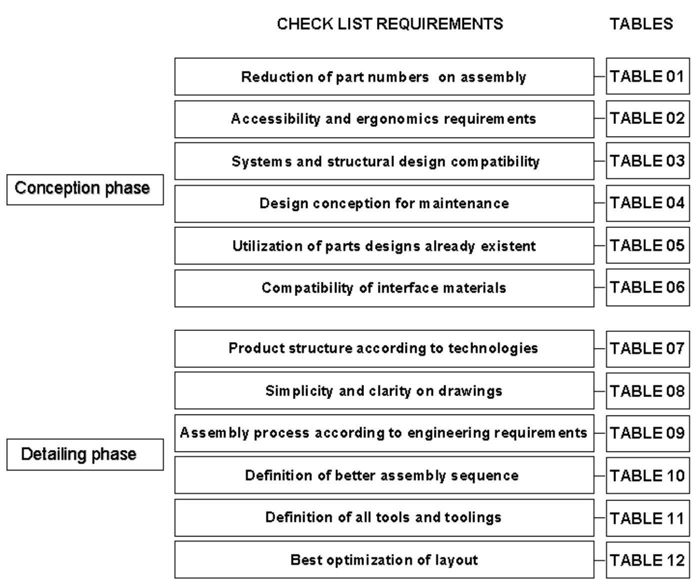


Figure 1. Structure of check list and tables set (DFMA guideline)

These 12 check list questions were defined because they are strongly related to the nature of the most common causes that generate direct impacts on manufacturing activities and maintenance services of aircraft.

This tool named DFMA guideline for engineers comprises 12 tables containing the list of checks to be followed by the engineer’s team members of integrated product development group. The information must be in consensus, integrated and be approved by the project managers.

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TABLE 01 goals to determine if the conception is being created as simple as possible for the reduction of parts. The simplification of product becomes the assembly easier and it helps the maintenance and replacement of components. The example of reduction parts showed below a micro switch that was simplified by the aggregation of 3 parts (a, b and c) in only one part (x) and also the elimination of rivets, fasteners, washers and nuts.

It reduced the manufacturing costs and made easier the assembly and maintenance requirements without affecting the functionability of the system (Figure 2)

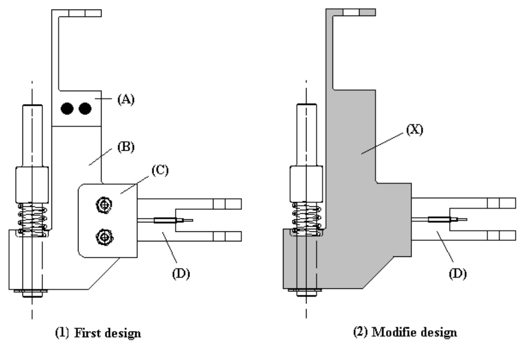


Figure 2. Reduction of parts on design

| Item | TABLE 01 – Number of parts | Effect of analyze fault |
|---|---|---|
| (a) | System components have related movement to the assembly | New part creation without necessity |
| (b) | Necessity of separated design components for facilitating the disassembly and removing | Difficulties during the maintenance tasks |
| (c) | Necessity of different material specification due to physical and chemical conditions | Increase of parts number for the assembly. |
| (d) | Possibility of using fit elements in substitution of fasteners | Unnecessary components on the assembly |

TABLE 02 goals to guide the designers about the accessibility and ergonomics condition of assembly people. The analyses define if the assembly is possible in some region, to promote the determination of how many people can occupy the same area during the defined time. It also helps to show the necessity of special tool development for a specific assembly and to support the definition of assembly sequence.

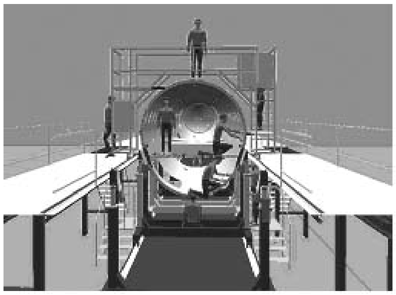

Figure 3. Ergonomics condition analyses

| Item | TABLE 02 – Ergonomics and accessibility | Effect of analyze fault |
|---|---|---|
| (a) | Existence of enough area on the assembly for not provide excessive physical strain to the people | Difficulties of positioning in some area and excessive and undesirable strain of the human body |
| (b) | Necessity to develop special tools for favoring the assembly and ergonomics condition | Impossibility of assembly and excessive and undesirable strain of the human body |
| (c) | Possibility of torque, sealing and lock wiring in fasteners and connections at all regions of assembly | Impossibility of assembly completion and inspection |
| (d) | Possibility to use equipments around the aircraft to favor the ergonomics condition | Difficulties of access and undesirable strain of the human body |

TABLE 03 aims to ensure that the conceptions of aircraft structure are designed to be compatible with aircraft systems, i.e., the interfaces are set correctly. Assemblies of aircraft systems like air conditioning, fuel, electrical, avionics, hydraulics, landing gear, engines, etc., must be guaranteed by the interface structural provisions.
The Figure 3 illustrates the compatibility between structural and fuel system design in one region of the tank.

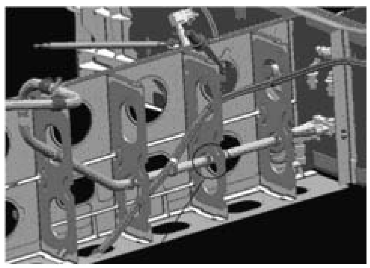

Figure 4. Fuel system installation

| Item | TABLE 03 – Compatibility between designs | Effect of analyze fault |
|---|---|---|
| (a) | Existence of supports on structural design to attend the systems installation | Impossibility for the systems installation |
| (b) | Existence of prepared areas for electrical bonding on structural and systems drawings | Necessities of reworks for assure the electrical current passage |
| (c) | Compatibility between sizes of fasteners attached on structure and fasteners for the systems installation | Impossibility of assembly and necessity of components changes |
| (d) | Compatibility between tolerances of assembly and parts | Occurrences of friction, adjusts and trimming |
| (e) | Necessity of interference analyzes for structural design with the interface systems | Occurrences of friction, gaps and steps between parts of the assembly |

TABLE 04 treats the points that must be observed during the design conception for facilitating the maintenance and aircraft services that will be present during the whole aircraft's life in operation. It is very important for avoiding customer blames because of difficulties with daily tasks, high cost of maintenance and operator services.

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| Item | TABLE 04 – Maintenance | Effect of analyze fault |
|---|---|---|
| (a) | Assuring for the removing and disassembly of parts | Difficulties during the maintenance and replacement activities |
| (b) | Possibility of simplification and visualization of the parts that need maintenance and periodical tests | Difficulties of comprehension and reading for the operator during the tasks |
| (c) | Possibility of using decals for maintenance indication advises | Maintenance and revisions done on late date |
| (d) | Possibility of using standard parts and easy of buying | Difficulties in case of replacement necessities |
| (e) | Possibility of designing parts that avoid wrong assembly | Probably occurrence of errors and increase of time during the activities |

TABLE 05 values the use of parts or assemblies of existing projects or similar geometry already used in other aircraft models. This practice will minimize design time and reduce costs with the development and qualification of new suppliers, providing significant gains in terms of design and manufacturing.
It is reached to use the maximum quantity of parts already existents and developed and also raw materials (aluminium, steel, titanium, etc.) and consumable materials like grease, sealants, paints, etc. used on other assemblies or projects.

| Item | TABLE 05 – Similar parts utilization | Effect of analyze fault |
|---|---|---|
| (a) | Possibility of using existent design of parts | Creation of a new part without necessity |
| (b) | Existence of part that attend the design requirements | Creation of a new part with the same geometry |
| (c) | The material of the part is compatible with the new requirements | Incompatibility of materials during the assembly |
| (d) | Possibility to buy raw material or part from a existent supplier | Development of a new supplier or subcontractor for the part |

TABLE 06 assists in the definition of raw materials to be used in parts and materials that work in contact. There should be a concern about the existent conditions on the interface regions between different materials. It will avoid future problems that can affect the life of components. An example of materials interface is showed in Figure 4.

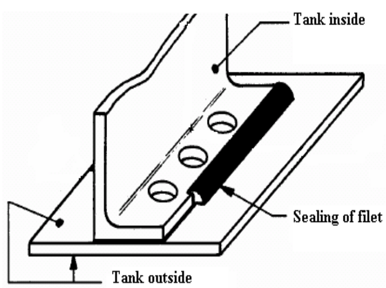


Figure 5. Interface materials

| Item | TABLE 06 – Material compatibility | Effect of analyze fault |
|---|---|---|
| (a) | Correct specification of metallic materials of interface | Possibility of stress and corrosion between parts |
| (b) | Correct specification of non metallic materials of interface | Possibility of damages on parts |
| (c) | Technical specification of consumable material (sealant, grease, paints, oil, etc). | Problems with protection and blocking |
| (d) | Existence of specified materials already registered and bought by the company | Increase of development time |
| (e) | Possibility of using alternative and replacement materials | Increase of development time |

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TABLE 07 reflects the relevance of care to be formed during the preparation of product structure, which is the list of all components to be used in a particular assembly of the plane. It is a database composed by the part numbers and ID parts linked between them. The product structure is created from the drawings for allowing at any time the information about the product configuration, applicability and models.

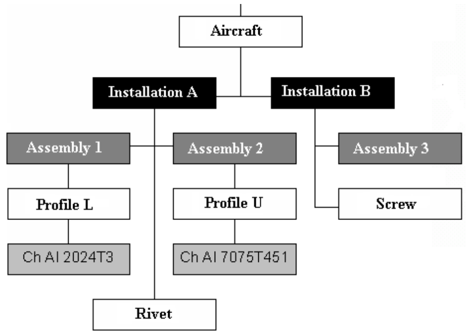


Figure 6. Model of product structure

| Item | TABLE 07 – Product structure | Effect of analyze fault |
|---|---|---|
| (a) | Creation and registration of parts and requirements in database in right time | Buy of material and manufacturing of parts in late time |
| (b) | Correct definition of each part according to the technological processes and manufacturers | Incorrect definition of manufacturers and assemblers |
| (c) | Definition of correct quantity of each component and manufacturing responsible | Problems with material suppliers and delays |
| (d) | Definition of parts applicability for utilization according to the aircraft models | Impossibility of issuing production orders |

TABLE 08 cites the most important points to be observed and incorporated into product designs, to minimize doubts and lacks of information during the time of assembly or manufacture. The drawings should represent graphically all technical needs of engineering to be performed to enable easy manufacturing of the product. Failures on drawings may represent problems at assembly line and to expend the manufacturing costs of aircraft because of product support needs.

| Item | TABLE 08 – Drawings | Effect of analyze fault |
|---|---|---|
| (a) | Quantity of part list components is according to the indication on the drawing | Doubts and possibility of unavailability of material at the assembly moment |
| (b) | Existence of all purchased items in company stock | Unavailability of material at assembly line |
| (c) | Representation of views, cuts and details on drawings according to necessity | Doubts and deficient information at assembly line |
| (d) | Representation of notes according to the design requirements | No technical information on drawings |

TABLE 09 includes the requirements to be applied during the preparation of procedures for production.
These outline scripts are used for manufacturing operations, assembly and tests, in addition to technical publications and services for maintenance of the aircraft. The scripts should only provide objective information, values and tolerances as well specified, using images if necessary and always reflecting the assembly engineering.

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| Item | TABLE 09 – Assembly procedures | Effect of analyze fault |
|---|---|---|
| (a) | Assembly processes is described according to the drawing information | Unavailability of information for the production |
| (b) | The steps define the better sequence for the assembly | Difficulties and errors during the assembly |
| (c) | Necessity of additional information (3D) on the assembly processes | Increase of time for drawings interpretation (2D) |
| (d) | Assembly processes contain all specified values of torque, pressure, flow, etc. | Unavailability of parameters for final conformity |

TABLE 10 focuses on topics of macro production flow, i.e., phases of the assembly lines and points to be considered for a suitable preparation of the sequencing of production tasks. The aircraft precedence's diagram estimates the cycle times of assemblies and tests, dividing the aircraft in work areas and studying the accessibility in each region. It goals to define the best sequence of assembly and test procedures, contributing to definition of cycle times x manpower for any assembly, layout and design of the production line for the use of tools and assembly jigs.

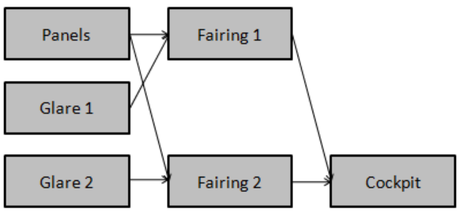


Figure 7. Assembly diagram

| Item | TABLE 10 – Precedent diagrams | Effect of analyze fault |
|---|---|---|
| (a) | Correct definition of technical assembly sequence of the activities | Difficulties for the management of production activities |
| (b) | Correct definition of prior and post assemblies | It can affect the assembly sequence |
| (c) | Definition and registration of number of people and hours for each assembly | It affects the production planning for the capacity of main power and hours |
| (d) | Definition and registration of work centers to be used | Unavailability of main hour and over time control |

TABLE 11 considers the importance to be given to the prediction of all tools and tooling required to perform the activities of manufacturing of parts, assemblies and aircraft maintenance. The ground equipments support are all devices designed to support the tasks of production, maintenance, repair, testing or inspection necessary to provide the manufacturing of the aircraft and keep it in perfect operating condition.

Figure 8. Assembly platform

| Item | TABLE 11 – Tooling | Effect of analyze fault |
|---|---|---|
| (a) | Specification of tools and tooling available on the market | Possibility of unavailability at the assembly time |
| (b) | Necessity for specifying special tools that are not available on the market | Impossibility of activities execution at the assembly line |
| (c) | Specification of support equipments like pressure set, hydraulic set, ground power unit, manometers, etc. | Impossibility of activities execution at the assembly line |
| (d) | Specification of jibs, stands, ladders, etc. | No resources for the production |
| (e) | Necessity of virtual simulation for the application of tooling in relation to the product | Incompatibility and friction of the tooling with the product |

TABLE 12 exposes the importance that should be given to the layout to be implemented on the assembly line. It will define the physical relationship between the production processes and determine the manner in which physical resources (material, information and people) will flow through the operation.

As a result, this analysis should be done comprehensively and with the best distribution as possible so that the best conditions are met. An optimized layout provides reduction of cost. An example of layout is showed in Figure 6:

Figure 9. Layout example

| Item | TABLE 12 – Layout | Effect of analyze fault |
|---|---|---|
| (a) | Studies for the better movement of the aircraft on the assembly line | Increase of time for movements inside the hangar |
| (b) | Definition of numbers of stations or docs to be used during the assembly | It affects the quantity of aircrafts foreseen to be deliveries |
| (c) | Flexible balancing of the activities, main power and positions of the aircraft | No definition about quantity of specialized people |
| (d) | Better disposition of consumable material shelves and tooling inside the hangar | Difficulties to get material and resources |

## 4. STUDY CASE

This case shows the progress and positive results achieved by the application of the proposed DFMA guideline as a tool of improvement.

The main goal was to modify the electrical system design of a small type of aircrafts.

### 4.1 Original design

The original design can be viewed in Figure 10:

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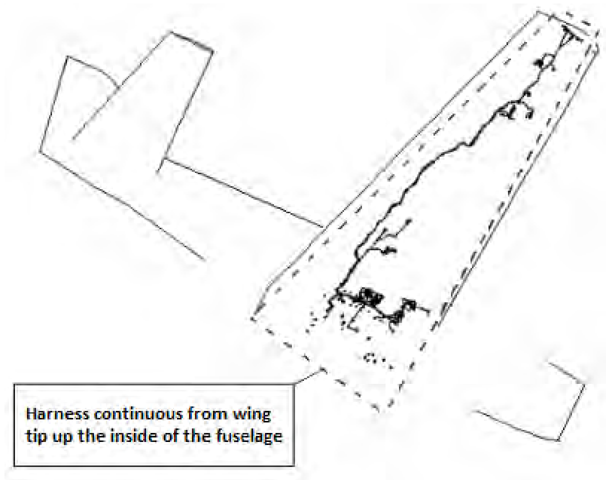


Figure 10. Original design conception

In this previous design the harnesses are continuous from the tip of the wings to the fuselage of the plane, which hampered the activities of manufacturing and services.
Because of that, the design was modified based on design for manufacturing and maintenance concepts, which also meet other requirements of DFX (Design for Excellence).

### 4.2 New design

For this design modification, the proposed DFMA Guideline for Engineers was applied through the following tables:

- Table 02 – Accessibility and Ergonomics requirements
- Table 04 – Design conception for maintenance
- Table 05 – Utilization of parts design already existent

The check list of each table were taken and used as a guide to drive the engineers to obtain a new project with the expected characteristics.
The improvement refers to the separation of harnesses that make the electrical connection between the fuselage and half-wings of the plane, through the implementation of interface connectors to provide partial installations in each segment and subsequent joining of them (Figure 11):

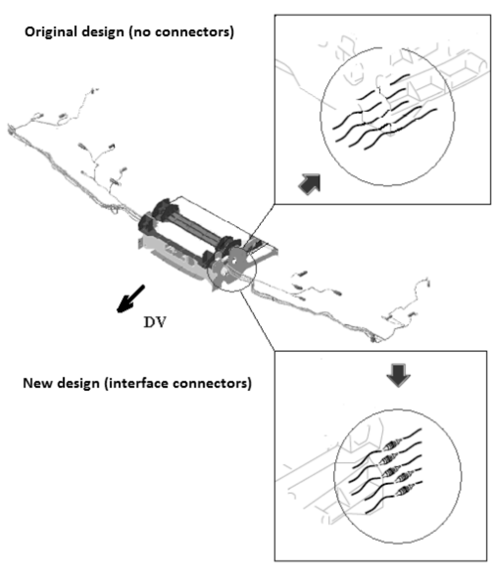


Figure 11. Comparison between original and new design

Based on plug in-play concept, the Table 05 was used for the definition of interface connectors, since the same part number is already used in other models of aircraft.
With the implementation of the new concept, it was possible to reduce 06 hours of cycle in final assembly for each aircraft produced because it is no longer necessary to have completed the installation of harnesses inside the fuselage (Figure 12).

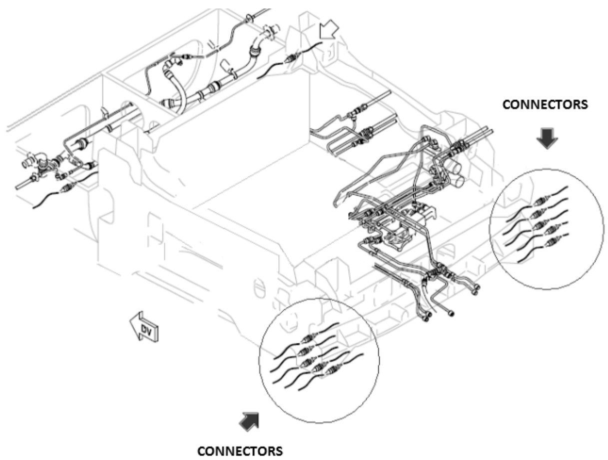


Figure 12. New design conception

The new conception benefits the fuselage stuffing activities related to accessibility within the structure and also the partial execution of tests systems, according to the requirements of Table 02.
Figure 13 illustrates the conception of the new design with the inclusion of interface supports on each half-wing roots.

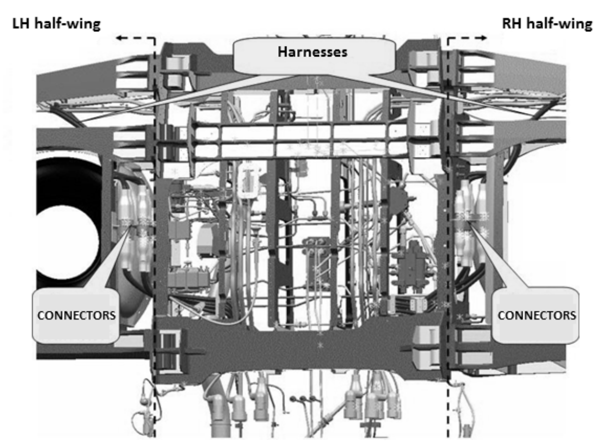


Figure 13. Interface connectors on half-wing roots

In addition, this new design improves maintenance activities in case of an eventual necessity of a half-wing removal or replacement. A simple decoupling of the interface connectors reduces time, makes the task easier and also requires a fewer people to perform the activity.

### 4.3 Gains achieved by DFMA Guideline application

After the implementation of this improvement redesign, the following results were achieved:

- Possibility of segments (half-wings and fuselage) stuffing separately and independently;
- Accessibility and easiness for systems installation;
- Reduction of cycle times and fewer people in final assembly;
- Easiness for maintenance activities in cases of harnesses repairs and troubleshooting;
- Possibility of the segments (half-wing and fuselage) separation, packaging and shipment to another place for subsequent reassembly and tests, without needs for disassembly of the systems already installed;

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- Provide improvements in interchangeability between equipped segments and support for spare parts;
- It favors the ergonomics and safety conditions.

## 5. CONCLUSIONS

This research work presented a customized tool for DFMA application in aeronautics industries.

It has been developed with the proposal to expand the application of DFMA methodology on product integrated development environment of aircraft manufacturers.

The development of this tool, herein named DFMA guideline for engineers, was based on rules and techniques of the DFMA methodology in conjunction with the needs of aeronautics industry and its importance of application.

Based on it, we developed the DFMA guideline for engineers for being used like a helpful instrument for dissemination and application of the DFMA methodology in the aeronautics industries. We also realized that the DFMA guideline for engineers can be used with more emphasis on following situations:

- Training instrument of DFMA methodology that guides the new engineers when working on product integrated development;
- Like tool of guideline for the most important steps to be followed during development phases, drawings conception and manufacturing processes;
- Like data input for storage of issues backgrounds and parts and assemblies revisions that compose the aircraft;
- Like database for consultations of the engineering department in case of further analyses and eventual modifications of design and improvements;
- Like complement for market software to maximize the benefits.

For being a specific and customized tool for aeronautics industries, the DFMA guideline for engineers helps for the identification e orientation to the solutions of manufacturing problems, most of cases difficultly identified through the exclusive analyzes with generic tools.

Finally, we can conclude that a tool like the DFMA guideline for engineers herein presented, attends most part of requirements for optimization and facilities for aeronautics design and it can easily used like a mean of diffusion of the methodology concepts and also to be a complement for the complexes cases that demand a more sophisticated and specific software.

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## 7. RESPONSIBILITY NOTICE

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