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"JÚLIO DE MESQUITA FILHO"
CAMPUS DE GUARATINGUETÁ

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Safety approach for interiors aviation engineering – design for cabin safety method

Guaratinguetá - SP
2020

Cesar Alberto Silva

**Safety approach for interiors aviation engineering –
design for cabin safety method**

Tese apresentada à Faculdade de Engenharia do Campus de Guaratinguetá, Universidade Estadual Paulista, para obtenção do título de Doutor em Engenharia Mecânica na área de projetos.

Orientador: Prof. Dr. Mauro Hugo Mathias (UNESP)
Co-Orientador: Prof. Dr. Luís Gonzaga Trabasso (ITA)

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ESTA TESE FOI JULGADA ADEQUADA PARA A OBTENÇÃO DO TÍTULO DE
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dedico este trabalho de modo especial, para milha família e para todos alunos que não conseguiram terminar seus cursos impedidos por quaisquer que sejam os motivos, que encontrem saber na vida e com este saber sejam felizes e construam também um mundo melhor.

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Thank you, Craig Yates

"É preciso ter asas, quando se ama o abismo."

Friedrich Nietzsche

RESUMO

Este trabalho traz para a indústria aeronáutica e para a academia um método para aumentar a aderência de requisitos de segurança de cabine ao produto final da engenharia de interiores de aviões, melhorando a qualidade técnica das soluções e reduzindo ciclos de desenvolvimento para novas configurações de interiores para aviões de transporte de passageiros. A pesquisa analisa os requisitos de aeronavegabilidade de interiores aplicáveis à segurança da cabine, os aspectos de ergonomia envolvidos no design de interiores e a origem da tecnologia de segurança de cabine. É discutido um aspecto de design conhecido como usabilidade e explica por que esse conceito é relevante para o projeto cabines de avião. Também são discutidos fatores humanos, erros humanos na segurança da cabine e conceitos relevantes que projetistas precisam considerar para projetos em segurança de cabine. Considerando os aspectos acima mencionados foi desenvolvido, descrito e aplicado um método denominado *Design for Cabin Safety*. O método que através de específicos passos objetiva aumentar a aderência de requisitos de aeronavegabilidade aplicáveis à segurança de cabine para projeto de interiores de aviões. Subsequente ao seu desenvolvimento o método foi aplicado em testes práticos em aeronaves reais e com diferentes usuários atestando sua praticidade. Desta forma a hipótese da tese foi explicada e a principal pergunta da tese foi respondida. A pesquisa termina com resultados, discussões e conclusão sobre o desenvolvimento e aplicação do método e sua contribuição em oportunidades para melhoria de segurança de cabine no processo de projeto de interiores de aeronaves.

PALAVRAS-CHAVE: Segurança da cabine. Projeto. Usabilidade. Fatores humanos. Ergonomia. Requisitos de aeronavegabilidade.

ABSTRACT

This work brings to the aviation industry and the academy a method to increase the adherence of cabin safety requirements to the final product of aircraft interior engineering, improving the technical quality of the solutions and reducing development cycles for new interior configurations for passenger transport aircraft. The research examines the requirements for interior airworthiness applicable to cabin safety, the ergonomic aspects involved in interior design and the origin of cabin safety technology. An aspect of design known as affordance is discussed and explains why this concept is relevant to the design of aircraft cabins. Human factors, human errors and relevant concepts that designers need to consider for cabin safety projects are also discussed. Considering the aspects mentioned above, a method called Design for Cabin Safety was developed, described and applied. The method through specific steps aims to increase the adherence of airworthiness requirements applicable to cabin safety for aircraft interior design. Subsequent to its development, the method was applied in practical tests on real aircraft and with different users attesting to its practicality. In this way, the thesis' hypothesis was explained and the main question of the thesis was answered. The research ends with results, discussions and conclusions about the development and application of the method and its contribution to opportunities for improving cabin safety in the aircraft interior design process.

KEYWORDS: Cabin safety. Design. Affordance. Human factors. Ergonomics. Crashworthiness requirements.

FIGURE LIST

TABLE LIST

ABREVIATIONS AND ACRONIMOS LIST

AC	Advisory Circular
ANAC	Agencia Nacional de Aviação Civil
CAD/CAM	Computer Aided Design/ Computer Aided Manufacture
CE	Concurrence Engineering
CFR	Code of Federal Regulation
IPD	Integrate Product Development
DF_CS	Design For Cabin Safety
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
HF	Human Factors
ICAO	International Civil Aviation Organization
IEA	International Ergonomics Association
OEM	Original Equipment Manufacturer (i.e. aircraft manufacturer; for example: Boeing Company, Airbus, Embraer etc.)
OWE	Over wing Exit
POET	Psychology of everyday things
RBAC	Regulamentos Brasileiros de Aviação Civil
R&D	Research and Development
Safety D	Safety Definition
SHEL	Software, Hardware, Environment and Liveware
TTL	Taxi and Take off Landing

LISTA DE SÍMBOLOS

§ requirement

CONTENTS

1 INTRODUCTION

1.1 MOTIVATION

Cabin Safety is a technology intrinsically linked to engineering and interior projects of aircrafts. It aims to protect all occupants of an aircraft (passengers, flight attendants and pilots) at all flight phases (takeoff, flight and landing).

Cabin Safety is present in all categories of aircraft or flight mission, i.e. commercial, executive and defense aviation. Among these categories, there are common needs that are present in all aircraft and specific needs according to the mission of the aircraft. It can be identified in various details present inside the aircraft such as seat belts, oxygen masks, emergency equipment, emergency exits on the wings, marks and placards with safety instructions or emergency procedures (eCFR — Code of Federal Regulations – www.ecfr.gov).

Cabin safety has its origin through investigation of aeronautical accidents where there were survivors. The analysis of the aircraft debris and injuries in survivors led to the identification of which changes in the design of the cabin the engineering should make that could result in fewer injuries to the passengers, consequently increasing the chances of their survival (Gangloff, 2013).

Cabin Safety can be encompassed in distinct but very related categories: safety during the flight and safety following a crash.

In-flight safety aims to protect the occupants of the aircraft from the effects of fire, turbulence, decompression and provide conditions to assist occupants in emergency situations. Safety following a crash involves protection against loads sustained during impact, providing conditions so that the passenger with no or few injuries can quickly get out of the aircraft (evacuate) and in case of fire, the interior material will delay in sparking the flame and propagating the smoke thus helping to make it possible for evacuation of the cabin (FAA – Fire and Cabin Safety Research Group - https://www.fire.tc.faa.gov/Cabin).

Cabin safety technology, among others, can be labeled as a passive technology, i.e. it does not operate in the various phases of flight such as landing gear, rudder or wing flap actuators. However, it allows a passenger to experience a strong turbulence in his/her seat inside the aircraft, an emergency evacuation or to open an emergency exit on the wing safely. The interior design can contribute positively or negatively to the survival of the passengers in normal or emergency situations, attesting that cabin safety is not passive technology but rather active and ready to meet the requirements that it has been designed.

The importance of this technology is easy to measure due to its relation to the survival of humans in normal or emergency situations that can be witnessed during a flight. Its complexity is related to the lack of a standard cabin design that ensures the success of its implementation in different aircraft models; aircraft interior design details are strictly related to cabin safety. Among the several works that seek to extend cabin safety can be mentioned: new materials for interiors, evaluation of human factors in emergency situations, design and layout of the monuments that make up the interior of the aircraft and its exits (FAA Fact Sheet, 2018).

The evolution of cabin safety in aircraft interior design is apparent. Analyzing the aircraft architecture and layouts of the 1940s one can now perceive the lack of knowledge of cabin safety of that period, where it was possible to find exposed metal structures, steps inside the cabin, unprotected lighting systems, various flammable materials and a layout which impedes evacuation (Figure 1). From this decade onwards, the use of the airspace as a means of transport has increased significantly. Unfortunately the number of accidents has increased as well; the positive part of this story is that the increasing investigation of these accidents resulted in lessons learned that were translated into engineering and design requirements for cabin safety.

Figure 1 - TWA - Vintage Photo of Cabin Meal Service

Source: Trans World Airlines (2017).

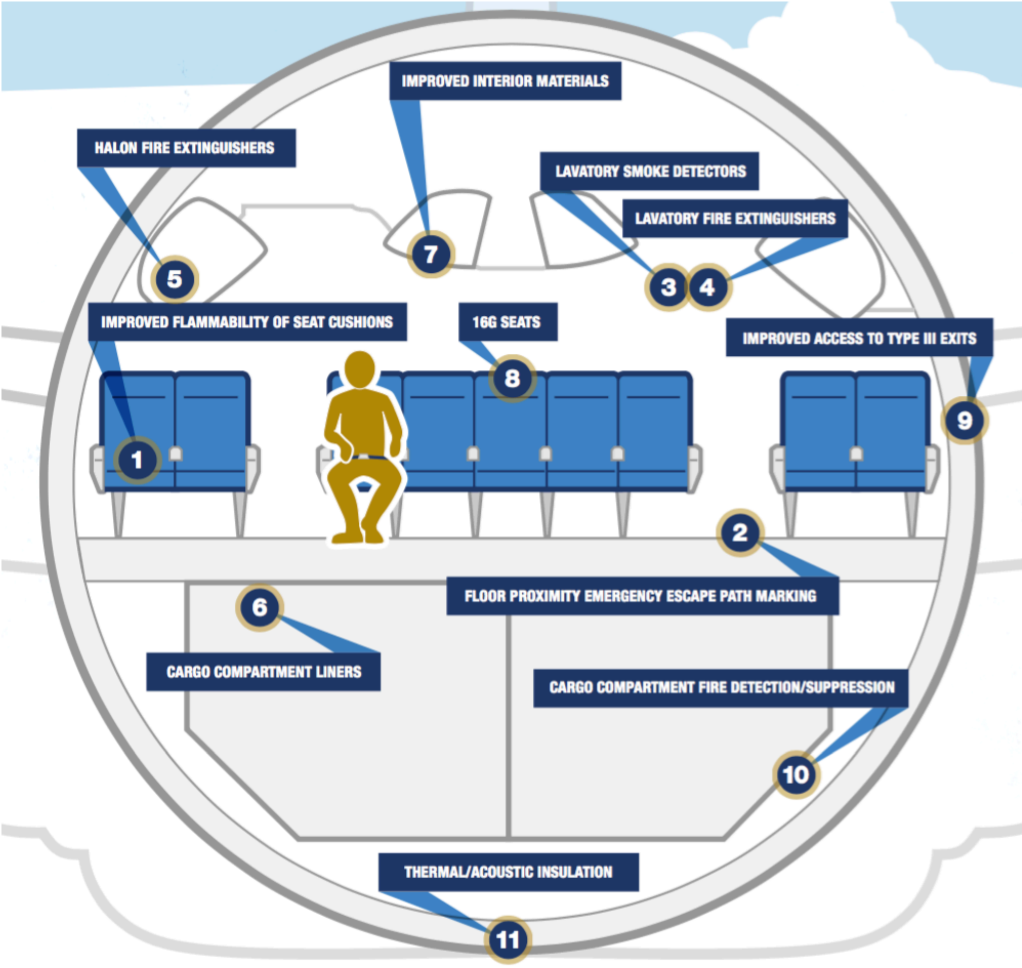
The search for better levels of cabin safety stimulate authorities and the aeronautics industry to constantly seek new materials with specific properties of fire resistance, materials with higher levels of absorption of impact loads, use of applied human factors in interior engineering and cabin design and operational procedures considering occurrences during flight and after a survivable accident.

The fatal air crash rate has begun to decline significantly since the 1970s; this was not accompanied by an equivalent reduction in the fatality rate of passengers aboard these aircraft (Kenji Toyama, 2006). The trend for air transport is continuing to grow that demands aircraft with increased seating capacity for passengers; demands by executive airplanes with cabins that meet the peculiarities of this aviation are also being projected, so the investment in the cabin safety study is of great interest for both the aeronautical industry and the public interest.

Faced with this challenge of transporting more passengers through air transport and ensuring passenger safety from boarding to final destination, cabin safety is an engineering and design technology that seeks to develop methods and design processes related to materials, human factors, and interior architecture aimed at a design concept that increases to the passengers safety in all phases of flight as well as comfort and entertainment in an airplane trip.

Over the years, the Federal Aviation Administration (FAA) has conducted extensive research and significant upgrades in cabin safety requirements to increase the likelihood of passenger survivability in aviation accidents. Many aviation accidents are survivable, and improvements to cabin safety and the prevention and control of in-flight fires have contributed to passenger survivability. The eleven areas depicted in (Figure 2) are examples of advancements in cabin safety (FAA Fact Sheet, 2018).

Figure 2 - Improvements to Aircraft Survivability



Source: FAA Fact Sheet (2018).

1.2 OBJECTIVE AND RESEARCH QUESTION

1.2.1 Objective

The overall objective of this work is to develop a method for integrating cabin safety requirements into aircraft interior design. If one considers that cabin safety certification requirements are known, the integrated product development process the interior engineering ought to assure that these requirements have adherence to the product. However as the interior requirements are in its majority performance based requirements, performance standards establish a required performance level, but do not specify the means by which that performance is to be achieved. So this is the particular challenge for interior engineering. As is better explain further here, the follow specific factors has influence in the success of the implemented solution for cabin safety like: emergency human behavior, the configuration to which the component is incorporated, the environment / situation that the component will be used and the usability of the equipment. The hypothesis that is assumed and demonstrated here is that executing this method in the initial phase of the product development, the cabin safety requirements adherence is increased and also designers and engineers with little experience benefits from using the method leading to delivering a safety configuration with short development cycle.

In order to achieve this, the following specific objectives have been identified:

1. Map the cabin safety requirements;
2. Develop the Design for Cabin Safety (DF_CS) method;
3. Apply the DF_CS method in real cases and discuss the results;
4. Identify opportunities for improvement in cabin safety.

1.2.2 Central question of research

The broader question considered central to this research is:
HOW TO INCREASE CABIN SAFETY THROUGH DESIGN?

The associated and subsequent issues are:

a) How can design benefit and its design details contribute to cabin safety?

b) How (what?) to improve the user's understanding (passenger, attendant) for the use of safety equipment and systems?

c) How to develop and apply methods to ensure that the interior and human factors requirements are efficiently kept in cabin design?

A shallow answer to this central question of research could be that simply: unfold the cabin safety certifications requirements into specific project requirements and demonstrate its compliance. Our more than twenty years of experience in interior engineering demonstrates that they are that simple. The essence of this work contribution is to allow the designer to systematically deploy and translate certification interior requirements into design requirements, to have criteria for prioritizing such requirements, as well as objective means of verification.

1.3 CONTRIBUTIONS

The design of an aircraft cabin, among others, has the challenge of ensuring that passengers understand and properly use safety equipment and systems. The final goal for this understanding and proper safety equipment use will be to offer to passengers resources to be in place during and after an emergency situation in flight or after a crash.

It was mentioned here that FAA has conducted extensive research to increase passenger survivability; it identified areas in the cabin that bring advancements in safety (FAA Fact Sheet, 2018). We could ask if the sum of these areas that improve safety or some areas are more relevant for safety than others. In addition, we could ask if prioritizing one requirement, we maximize its beneficial results. This kind of question is present daily in the interior engineering office.

The SAFETY SCIENCE community released a lot of papers about Safety Science on Safety in Design (Safety Science, 2007) - were the mass introduction of new technologies in industrial production systems <more automation (CAD/CAM), more information technology> has increased the performance of these systems in terms of quality, productivity, flexibility and availability. However, it has introduced a number of difficulties in design integration (of safety and human factors), design adherence in all involved requirements, designer thought process about safety, proof in practice versus scientific approach etc. According to these findings we could formulate other questions as to what extent is possible to incorporate safety in design? Using what methods?

The practical aircraft interiors design community is witnessing positive and negative results aiming at the incorporation of safety requirements into interior design. As we only have the whole interior assembled in the last phases of the aircraft production line, sometimes the negative results ultimately were identified only during the test simulating final user utilization of the equipment or system. In these cases of negative results, we returned to the first question of this chapter about which requirement (or design aspect) we should pay more attention to or which combination of requirements or design aspects we must capture in the design to transform negative into positive results, and consequently lead the final user (usually the passenger) to properly use the equipment or system.

This work has a relationship with FAA intent, with Safety Design, and our daily challenge at Embraer Interior Engineering, being motivated by these questions.

The contribution of this work is the ***Design for Cabin Safety Method*** (that with elucidation of airworthiness requirements for cabin safety combined with conception of the affordance in design) intends to create a method to better identify and capture requirements and affordability of safety equipment in its design and use. In our research as is showed in chapter 2 - Table 2.2, it was observed that the safety requirement adherence in the final product and procedures contributes to reduce aircraft passengers harm in a survivable accident.

It is demonstrate through some test cases and method validation what happens before and after the method use. Moreover, in our research for theoretical foundation, it was observed in the cabin safety technology the lack of a specific method that systematically unfolds and/or translates the airworthiness requirement into design requirement, prioritizing and evaluating the adherence of these requirements into the final product; this is be present in the method developed herein.

1.4 STRUCTURE OF THE THESIS

This thesis is constituted by five chapters including: the Introduction – Chapter (1) that presents the motivation of the contextualization of the problem and the needs that motivated the work objective; the central question of the research and some sub questions that intend to cover associated aspects and contributions where it identifies other research related with this work and introduces the developed method that is the core of this research and finally the motivations that contribute and drive the development of this thesis.

In Chapter (2) a theoretical basis is presented through a bibliographic review about air transport, a review on aeronautical accidents as they are classified and analyzed and what contribution these bring to the cabin safety project, a review on the research in Cabin Safety by industry, certification authorities and by associations and universities that are interested in this technology. And lastly a review regarding cabin safety culture in the aviation industry.

In Chapter (3) is presented the development of the Design for Cabin Safety method with its constitutive steps.

Chapter (4) presents the DF_CS method application in test cases that the interior engineering is required to perform to release the use (certify) of the cabin, in accordance with the requirements issued by the aeronautical certification authorities. It is also presented a case study with different specialists using the DF_CS method. And lastly an analysis of the method application and its results.

In Chapter (5), the work results and conclusion are presented. This contains the answer to the central question of the research, main results obtained, limitations of the work and proposal of future developments.

2 THEORETICAL FOUNDATION

This chapter presents the theoretical foundation for this research that is composed of the following sections: introduction to airworthiness requirements specific for the cabin, an overview to aircraft cabin ergonomics, a brief history of the origin of cabin safety in aviation, the introduction and succinct explanation about affordance, the aspects of human factors and human error in cabin safety and a bibliographic review about cabin safety and its design.

2.1 AIRWORTHINESS REQUIREMENTS, ERGONOMICS AND CABIN SAFETY ORIGIN

2.1.1 Airworthiness requirements

The airworthiness requirements define the minimum level of safety applicable to an aeronautical product. Airworthiness means that the aircraft conforms to its type design and is in a safe operating condition. Therefore, the Airworthiness Requirements provide acceptable certification methods for demonstrating compliance to certify an aeronautical product.

Demonstrating compliance with these requirements is part of the daily work of engineers, and designers in the aeronautics industry. Specifically, for interiors including interior structures and cabin safety, the requirements are entitled Crashworthiness.

Crashworthiness applied to the aircraft cabin means to introduce into the design of interior structures considerations pertaining to the protection of occupants in a "survival environment" as if it were a formula one car cockpit. A crashworthiness environment that was designed with the concept of crashworthiness does not subject occupants to crash forces (during a crash landing) that exceed human tolerance levels and ensures that the structural integrity of the passenger space remains intact (or with minimal damage) so that occupants with no or minimal injuries can quickly evacuate the aircraft (AC 25-17A, 2009). In the previous sentence the words "quickly evacuate the aircraft", denote another part of the crashworthiness concept, this fast mode of evacuation is obtained by complying with cabin safety requirements, which is clarified in this work.

Therefore, the legal aspects that the interior of the cabin must adhere to are defined within the requirements for Crashworthiness. Regulatory authorities are responsible for issuing these requirements and also for verifying compliance with them. Aircraft manufacturers must demonstrate compliance with these requirements to receive authorization to market their airplanes to carry passengers.

In Brazil we have the Agência Nacional de Aviação Civil (ANAC) that regulates our civil aviation. Among other regulations, it publishes and updates the Regulamento Brasileiro de Aviação Civil (RBAC) where "PART 25" titled: Airworthiness Requirements: Airplanes Category Transport. It is relevant to mention that inside the RBAC there are others parts for other aircraft categories, for example PART 23 is the regulation that governs small aircraft thus PART 25 is the regulation that governs transport category aircraft.

In the RBAC in paragraph (A) General, it is stated: For the granting of type certificates for transport category airplanes, Title 14 Code of Federal Regulations (CFR) Part 25, Amendment 25-134, of the Civil Aviation Authority, Federal Aviation Administration - FAA, Department of Transportation of the United States of America in vigor since August 8, 2011 shall be adopted in full in the English language. This PART 25 contains all the airworthiness requirements for all existing technologies present in a transport category aircraft. Subpart D - Design and Construction contains the majority of the requirements associated with cabin safety technology.

There is no intention in this work to describe and explain all of the cabin safety requirements. However, in Table 2.1 has the requirements for interior structure and cabin safety that are the requirements most pertaining to this research. In addition to these requirements exist Advisory Circulars (AC) that provide acceptable certification methods, but not necessarily the only acceptable methods, for demonstrating compliance with the crashworthiness requirements for transport category airplanes. The guidance in this AC is not mandatory nor a regulation however is very helpful for aircraft manufacturers, modifiers, foreign regulatory authorities, and FAA transport airplane type certification engineers, and their designees. Specifically for interior engineering there is AC No: 25-17A – Transport Airplane Cabin Interiors Crashworthiness Handbook. Another document commonly issued by regulatory authorities are the Issue Papers that for situations where the current requirements do not provide sufficient information for the applicant to show compliance with the applicable requirements the agency issue an appropriate document for the applicant to follow.

Table 2.1 – Airworthiness requirements for Cabin Safety

PART 25—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

Subpart D—Design and Construction	
General	
§25.601	General.
§25.603	Materials.
§25.605	Fabrication methods.
Emergency Landing Conditions	
§25.561	General.
§25.562	Emergency landing dynamic conditions.
§25.563	Structural ditching provisions.
Personnel and Cargo Accommodations	
§25.771	Pilot compartment.
§25.772	Pilot compartment doors.
§25.773	Pilot compartment view.
§25.775	Windshields and windows.
§25.777	Cockpit controls.
§25.779	Motion and effect of cockpit controls.
§25.781	Cockpit control knob shape.
§25.783	Fuselage doors.
§25.785	Seats, berths, safety belts, and harnesses.
§25.787	Stowage compartments.
§25.789	Retention of items of mass in passenger and crew compartments and galleys.
§25.791	Passenger information signs and placards.
§25.793	Floor surfaces.
§25.795	Security considerations.
Emergency Provisions	
§25.801	Ditching.
§25.803	Emergency evacuation.
§25.807	Emergency exits.
§25.809	Emergency exit arrangement.
§25.810	Emergency egress assist means and escape routes.
§25.811	Emergency exit marking.
§25.812	Emergency lighting.
§25.813	Emergency exit access.
§25.815	Width of aisle.
§25.817	Maximum number of seats abreast.
§25.819	Lower deck service compartments (including galleys).
§25.820	Lavatory doors.
Fire Protection	
§25.851	Fire extinguishers.
§25.853	Compartment interiors.
§25.854	Lavatory fire protection.
§25.855	Cargo or baggage compartments.
§25.856	Thermal/Acoustic insulation materials.
§25.857	Cargo compartment classification.
§25.858	Cargo or baggage compartment smoke or fire detection systems.
§25.859	Combustion heater fire protection.
§25.863	Flammable fluid fire protection.

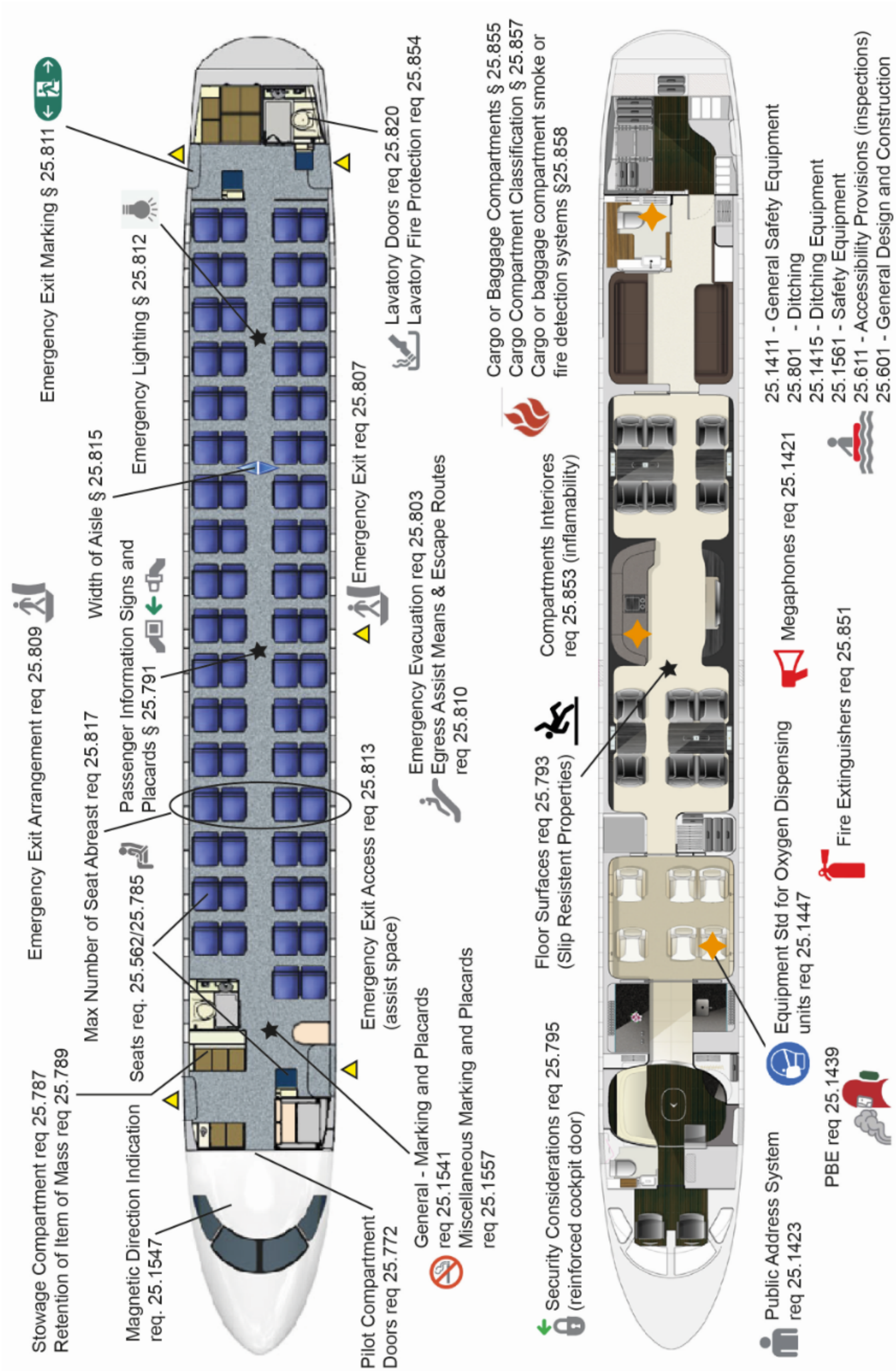
Fire Protection	
§25.865	Fire protection of flight controls, engine mounts, and other flight structure.
§25.867	Fire protection: other components.
§25.869	Fire protection: systems.
Subpart F—Equipment	
General	
§25.1301	Function and installation.
§25.1309	Equipment, systems, and installations.
Safety Equipment	
§25.1411	General.
§25.1415	Ditching equipment.
§25.1419	Ice protection.
§25.1420	Supercooled large drop icing conditions.
§25.1421	Megaphones.
§25.1423	Public address system.
Subpart G—Operating Limitations and Information	
Markings and Placards	
§25.1541	General.
§25.1543	Instrument markings: general.
§25.1557	Miscellaneous markings and placards.
§25.1561	Safety equipment.

Source: CFR 14 – FAA PART 25 Subpart D – Design and Construction (2018).

In Figure 3 the applicability of interior requirements for aircraft areas is graphically demonstrated. The figure also shows the airworthiness requirement associated with each component, monument or cabin area present in a conventional interior configuration for commercial (the upper part of the figure) and executive jets (the lower part of the figure). The standards interior monuments that compose a cabin interior are:

- seats (passenger seat, pilot seat and flight attendant seat);
- divans (or sofas - that are common in executive jets)
- dividers (or bulkheads);
- emergency equipment;
- galleys;
- lavatories;
- baggage compartments accessible by the cabin;
- stowage compartments (overhead beans for commercial jets and credenza for executive jets);
- marks and placards;
- illuminated signals like emergency exit indication (green man running);
- main door and over wing exit;

Figure 3 - Interior Configuration with Applicable Requirements



- cockpit.

Source: Adapted from Embraer and updated with requirements by the author (2017).

2.1.2 Ergonomics

According to the International Ergonomics Association (IEA) definition: Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people (IEA, 2019)

The necessities of passengers inside an aircraft prior, during and after the flight are diverse, and to properly comply with these necessities the interior designers shall be aware with ergonomic aspects.

Passenger seats could be considered a work place, an armchair for reading, or a kitchen chair. Consequently there are ergonomic requirements for all of these needs, and the ergonomic requirements shall be combined with crashworthiness requirements that will protect each occupant during an emergency landing allowing them to properly evacuate the aircraft. In this work, the ergonomic aspects mentioned are the ones related to the ergonomics that add value to the safety aspects.

According to the interior requirements quoted in section 3.1, a vast part of cabin interior features shall consider ergonomic aspects in their design. For example considering Emergency Exit Arrangement Requirement <14 CFR PART 25 - requirement number 25.809>, the requirement states:

(a) Each emergency exit, including each flight crew emergency exit, must be a moveable door or hatch in the external walls of the fuselage, allowing an unobstructed opening to the outside.

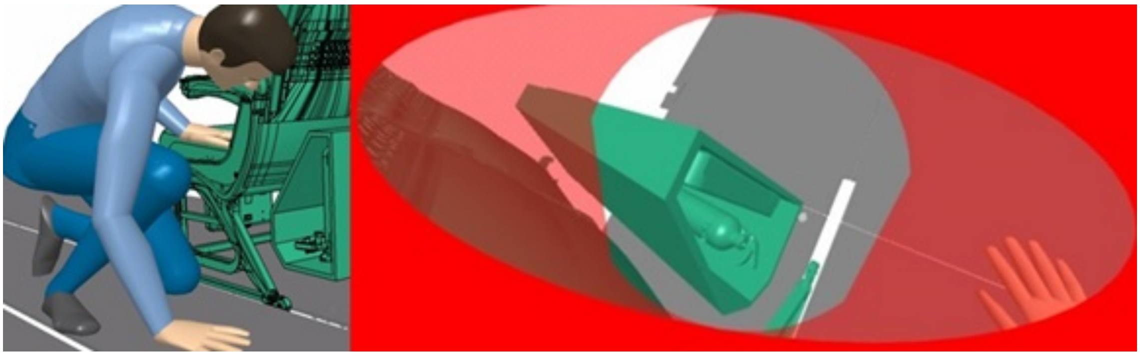
(b) Each emergency exit must be openable from the inside and the outside.

(c) The means of opening emergency exits must be simple and obvious; may not require exceptional effort; and must be arranged and marked so that it can be readily located and operated, even in darkness.

Based on the ergonomics definition, it is possible to observe that in order to show compliance with aeronautical interior requirements the aircraft manufacturer (OEM) shall also to comply with ergonomics requirements. This shows the relevance that ergonomics has for cabin safety.

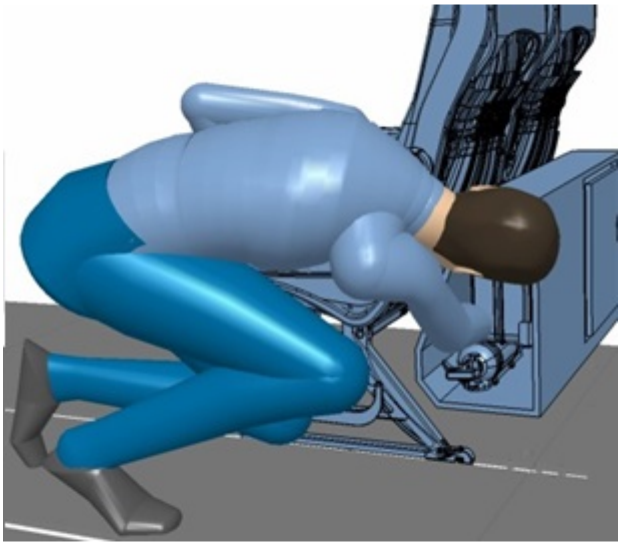
Figures 4, 5 and 6 are illustrations from interior engineering virtual analysis to assess if the emergency equipment is ergonomically installed in addition to assessing if they are complying with accessibility requirements.

Figure 4 - Ergonomics Assessment - Scene A



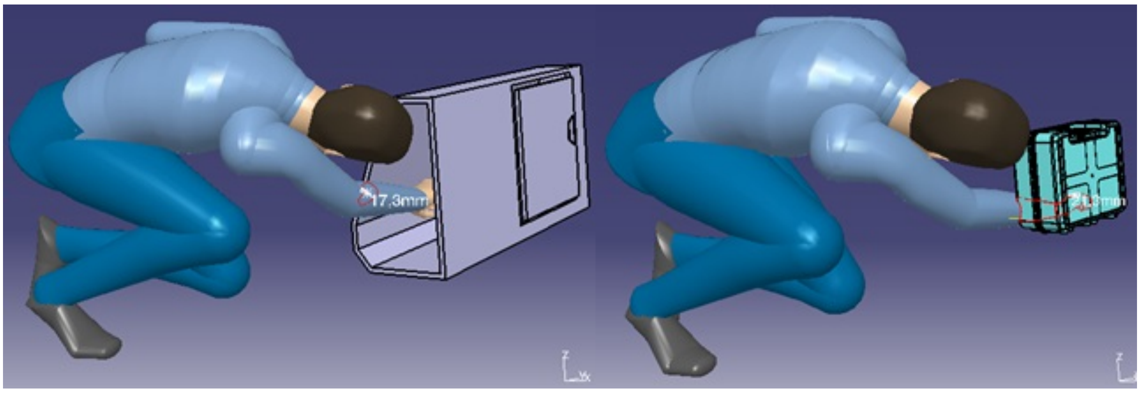
Source: Adapted from Embraer Dog House Ergonomic Evaluation (2018).

Figure 5 - Ergonomics Assessment - Scene B



Source: Adapted from Embraer Dog House Ergonomic Evaluation (2018).

Figure 6 - Ergonomics Assessment - Scene C



Source: Adapted from Embraer Dog House Ergonomic Evaluation (2018).

2.1.3 Cabin safety origin

Recently a meeting was held at Embraer with cabin safety engineers, designers and specialists to discuss, evaluate and develop a proposal to consolidate the roles, responsibilities and performance for the technology of cabin safety within the aircraft manufacture organization. The workshop objective was to enhance cabin safety current practices and to expand the support to new aircraft development programs and for the fleet. The workshop started with an open and productive debate regarding what cabin safety really is: it is a technology, a division of the interior engineering or a discipline of safety. Based on 40 years of Embraer experience in this area and in outside studies regarding this subject the conclusion was that Cabin Safety is a Technology.

Searching the definition of "technology" it is possible to find numerous definitions. The simplest and didactic definition found is one that mentions that "technology makes our life easier or solves problems".

Another stimulating question was: considering cabin safety as a technology, what is this technology and what does this technology require? Based on this research, I found that to answer these questions it is important first to define some of the key terms as follows:

Cabin is the area where passengers sit in an airplane[1] (Cambridge Dictionary).

Safety is freedom from unacceptable risk.

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[1] For the purpose of this study, cabin is where passengers may stay during all flight phases considering lavatories, galley area or if it is in an executive configuration there is a bedroom, shower area etc.

Risk is a combination of the probability of occurrence of harm and the severity of the harm (Kinnersley, 2007).

Thus, these definitions contribute to answer the question: What does this technology require? This technology wants to develop a cabin that reduces the risk to harm passengers during all flight phases. It is strictly related with *Crashworthiness research*.

The Origin of Crashworthiness Research

The researcher Hugh DeHaven Jr. (1895-1980) is considered "The Father of Crashworthiness Research". He was a pilot and mechanical engineer who survived from an accident when he was training gunnery runs with his airplane as a target. Two aircraft collided and the plunged 500 feet to the ground. The gunner died but DeHaven survived. His examination of the wreckage convinced him that his most serious injuries had been caused when the massive, pointed buckle on his "safety" belt penetrated his abdomen, rupturing his liver, gall bladder, and pancreas (Gangloff, 2013).

Focused on injury prevention, DeHaven theorized that redesigning or reconfiguring elements in the plane's interior might prevent injuries. As he explained, "it suddenly dawned on me that you can't say that an accident produces injury because an accident can also produce great safety." (DeHaven, 1968). This insight propelled him into his life's work: the epidemiology of accidents. He believed that statistical analysis would enable engineers—aeronautical and automotive engineers in particular—to eliminate hazardous design features.

In 1936 DeHaven used his kitchen as a laboratory, dropping eggs onto a slab of half-inch foam to determine the distance at which the foam would cease to protect an egg from breaking. He stopped at the height of ten feet (the limit of his ceiling) with all eggs intact. As he noted, the experiment demonstrated that while a delicate item required some cushioning, the amount of cushioning need not be great. When DeHaven repeated the experiment outside Cornell University Medical College in 1947, he and his staff dropped eggs onto a three-inch rubber mat from a height of 100 feet; even though they fell at speeds greater than fifty miles per hour and re-bounded some thirty feet up before being caught, the eggs did not break. This one experiment had vast potential for safety engineering: if as delicate a thing as an egg could survive a significant impact with minimal cushioning, then the mechanical velocities created during the twentieth century did not have to be deadly. (Gangloff, 2013)

After the egg experiment DeHaven started researching the human body to demonstrate that bodies could behave in a similar manner when properly protected. He developed the similarity conception between the egg shipping foam crates and the aircraft, considering that the cabin design shall include features that will protect the human body in the crash event. As mentioned in section 3.1, cabin safety technology has their specific requirements that constitute the basis for Crashworthiness. As illustrated in Figure 7, the airplane cross section was conceived to have a geometry that in case of crash landing will protect passengers similarly to the egg crate.

Figure 7 - Aircraft Configuration and Egg Crate

Source: Adapted from Embraer E1 Cross Section for marketing and eggs crate (2018).

The FAA Cabin Safety Research Technical Group[2] described that cabin safety can be classified into two distinct, but largely interrelated, categories: *in-flight safety* and *post-crash* survival. The primary focus of cabin safety is the safety and survivability of airplane occupants.

Research activities aimed toward in-flight safety address fire hazards, protection against turbulence, decompression, and human factors concerns related to occupants, that concentrate on general design practices (e.g. no sharp edges or tripping hazards). Research activities aimed toward post-crash survival include crash (impact) protection, emergency evacuation, water landings, and post-evacuation survival, especially in harsh environments (e.g., fire, remote areas, water). (FAA, 2019)

[2] https://www.fire.tc.faa.gov/cabin.stm

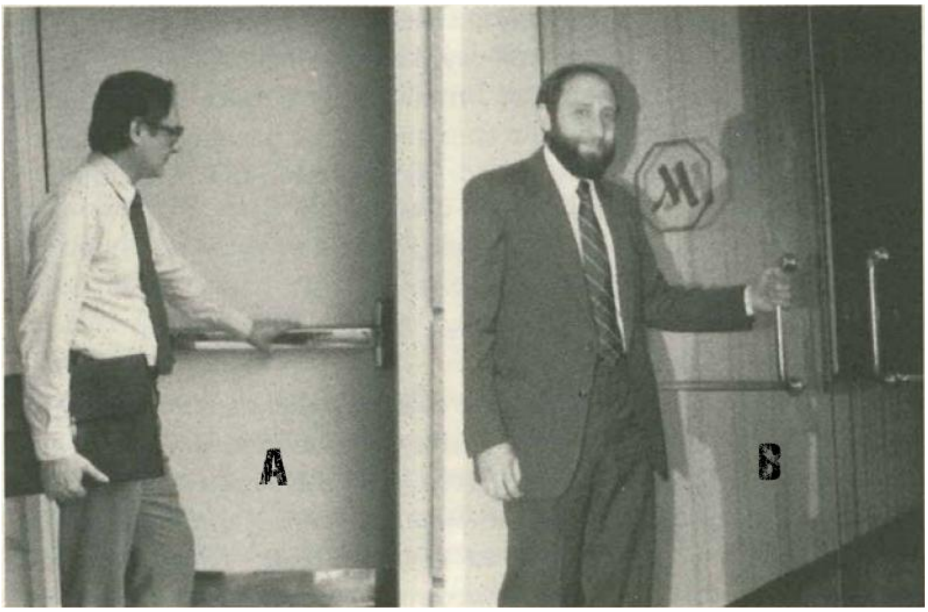
2.2 DESIGN CONCEPTION

2.2.1 Affordance – the psychology of how people interact with things

Donald A. Norman is a designer that became famous with his research regarding "The Design of Everyday Things". The outcome of his research has produced a book with same title. His research and book are about the Psychology of Everyday Things (POET). POET emphasizes the understanding of everyday things, things with knobs and dials, controls and switches, lights and meters. He quotes that the examined examples have demonstrated several principles, including the importance of visibility, appropriate clues, and feedback of one's actions. These principles constitute a form of psychology – *the psychology of how people interact with things* (Norman, 2002).

Norman brought to design an important psychological concept of visual perception that is known as *AFFORDANCE*. To distinguish affordance and usability in summary it is possible to quote that a design that achieves good usability structures affordances in ways advantageous to the user's goal. Norman mentioned that: there already exists the start of a psychology of materials and of things, the study of affordances of objects. When used in this sense, the term affordance refers to the perceived and actual properties of a thing, primarily those fundamental properties that determine just how the thing could be possibly used (see Figure 8).

Figure 8 - Affordance of Doors



Source: Donald A. Norman (2002).

Door hardware can signal whether to push or pull without signal. The flat horizontal bar of A affords no operations except pushing: it is excellent hardware for a door that must be pushed to be opened.

The door in B has a different kind of bar on each side, one relatively small and vertical to signify a pull, the other relatively large and horizontal to signify a push. Both bars support the affordance of grasping: size and position specify whether the grasp is used to push or pull – though ambiguously.

Affordances provide strong clues to the operations of a thing. Plates are for pushing, knobs are for turning, slots are for inserting things into, and balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instructions are required. Complex things may require explanation, but simple things should not. When simple things need pictures, labels, or instructions, the design has failed (Norman, 2002).

Inside an aircraft cabin interior there are a lot of “every flight things” that shall be operated by crew and/or by passengers. Sometimes these things are specifically for comfort, like the bottom to recline your seat, and sometimes these things are for safety, like the seat belt. However, safety features shall have affordance and consequently be simple and obvious to use or to operate.

For cabin interior designers and for cabin safety specialists we have an intricate "relation" with this concept *simple and obvious*. It may sound quite understandable but in some instances is not so clear. This conclusion has been building through this research and through several projects developing "in flight things" to be used for safety.

In fact, the term simple and obvious is part of the requirement that any aircraft manufacturer shall demonstrate compliance for an exit design. The requirement for Emergency Exit arrangement states that: "*The means of opening emergency exits must be simple and obvious; may not require exceptional effort; and must be arranged and marked so that it can be readily located and operated, even in darkness. Internal exit-opening means involving sequence operations (such as operation of two handles or latches, or the release of safety catches) may be used for flightcrew emergency exits if it can be reasonably established that these means are simple and obvious to crewmembers trained in their use.*"

The challenge is how to design a means of opening emergency exits and later how to demonstrate that this design is simple and obvious to operate. Aircraft manufacturers shall be extremely careful regarding this design and later shall demonstrate that the exit is complying with this requirement. This demonstration is through test using naïve subjects to operate the exit door. The use of naïve subjects to demonstrate compliance have included in interior design process another aspect know as Human Factors, which is another vast field of study.

In conjunction with the Donald A. Norman conception it was observed that interior designers shall pursue to design interior safety features with affordance. This affordance concept will "gives" to *cabin things* the design, the size, the position, the format that allow it to be used in a proper, simple and obvious way.

Andrew Hale, a safety expert, in his paper: "Safety by Design: were are we now?" mentioned that designers shall assimilate that they are not (or should not be) just designing hardware, but should, as far as possible, see their task as designing the behavior which uses the hardware safely (Hale, 2007).

2.2.2 Human factors and human error in cabin safety

In the section above it was introduced the affordance concept, also it was mentioned that some cabin features shall demonstrate that are simple and obvious to use (i.e. have affordance). One way to demonstrate the compliance with this requirement presented in table 2.1 is via test using naïve subjects (representing aircraft passengers) to perform the operation. This brings to cabin design the human factor considerations that shall be present in all cabin interior project phases. The level of understanding of human factor fundamentals and concepts will contribute to the success or to the failure in providing clues to passengers for proper use of cabin features, dictating his behavior in normal or emergency situations.

2.2.2.1 Human factor in cabin safety

According to International Civil Aviation Organization (ICAO, 2002) human factors is concerned with people in their dynamic working environments; about their diverse relationships with the technological elements, with procedures, and with the environment of the civil aviation system; and also, with their relationships with other people. These include human behavior; decision-making and other cognitive (i.e., mental) processes; the design, learnability, maintainability, and usability of controls and displays; flight deck and cabin layouts; communication and software aspects of computers, maps, charts and documentation such as aircraft operating manuals, standard operating procedures, checklists, etc (ICAO, 2003).

It is also mentioned that the human element is the most flexible, adaptable and valuable part of the civil aviation system. But it is also the *most vulnerable to influences that can adversely affect its performance*. With the majority of accidents and incidents in the civil aviation system resulting from less than optimal system performance, there has been a tendency to attribute them to human error. However, the term “human error” is of little use in accident prevention and mitigation. Although it may indicate where in the system the breakdown occurred, it provides little indication as to why it occurred. An error attributed to the human component of the system may have been design-induced or associated with inadequate or inappropriate training, badly designed or implemented procedures, or a poor layout of checklists or manuals (ICAO, 2002).

In contemporary safety thinking, human error is the starting point rather than the end point in accident prevention and mitigation. (Dekker, 2001).

It is possible to observe that human factors or human behavior is important for safety and shall be considered as additional requirements for cabin design.

A point of attention in cabin design conception considering human behavior is because the designers that are designing some new feature or improving its design have strong familiarity how to use or manipulate this hardware, overlooking how others will learn its usability. An appropriate approach, apparently obvious but that must be considered part of the design validation, to prevent this is to think and design considering the passenger viewpoint and its naivety on board. One suggestion, to convert this relevance in design, based on our experience and in the reviewed literature is to adopt the strategy to constantly test the design conception (in all design phases) with naïve subjects. This could protect the interior engineering office regarding the surprise that a feature, when installed in an aircraft, wasn't operated by the final user (passengers) as intended by design. This evaluation with naïve subjects could be a detailed test representing with fidelity the final interior configuration or a simple evaluation with colleagues from the office, depending on the level of feedback required.

The specialists (designers and engineers), during a cabin interior development, shall consider certification requirements, customer requirements, aesthetical aspects, ergonometric dimensions, structural constraints, however they imagine based on their own concepts that the final user behavior will follow exactly the procedure that he/she has conceived for that project. It is noticeable, based on discussions with these specialists (after the project finish) that they have high confidence that the their design conceptions are obvious to use. The scenario starts to change when naïve subjects are called to perform the procedure or to use some specific safety device.

Inside a cabin interior there are didactic examples illustrating how human behavior responses play a significant role in cabin safety. We need to remember that some procedures on board are performed in emergency situations where the human response will vary as well.

The examples below, within the context of our research, are tests performed in the certification phase for a specific aircraft interior. It addresses some, but not all, aspects of human behavior in cabin safety.

2.2.2.2 Human error in cabin safety

During the development and the certification phase interiors engineers have to perform cabin safety tests (some of them were mentioned before) for specific tests required to use volunteers to validate specific design conceptions.

Based on this research and evaluating cabin safety test results, it is possible to observe a different kind of volunteer's behavior that may result in a test passing or failing. As in life, when we succeed, we celebrate. When we fail, we evaluate why the failure has occurred. An evaluation about the root cause of failure is not a simple and logical process when there are humans actions involved. The designers and engineers responsible for the project that is being tested are so optimistic about their technological solutions and have the tendency to attribute upon volunteers the test failure (human error). It is common to hear: “it was so obvious”, “why s/he did not follow the instructions”, “s/he was nervous and did not pay attention to what they were doing”, etc.

Currently research related with Human Error is a vast field. In this vast universe of theories and facts, we tried to extract an appropriate conception for this research connecting cabin safety design and human error.

In the paper Psychology and Design Processes, the psychologist and researcher Bernhard Wilpert defines human errors as an action not reaching its intentions (Wilpert, 2007). He did an analogy between design and human error and defined a design mistake “as a feature of a design which makes it unable to perform according to its specifications”. Or rather pragmatically a design error has occurred, “if the design or operating procedures are changed after an incident has occurred”. Bernhard Wilpert describes aspects related with the design process and psychological contributions that necessarily have to be incorporated in it. The psychological perspectives, as observed during the cabin safety tests, are beneficial for the design with the objective to improve safety in the cabin.

In his review and reflections, Wilpert suggested some points of attentions listed below:

- relationship between creativity and successful design (some cognitive factors may impede creative solutions to given design problems);
- the development of the adequacy of mental models that designers need to adopt to understand how final user will behave or will operate an specific feature;
- more methodological considerations when design a sequence and interrelationships steps to perform a procedure or task (i.e. to open an emergency exit);
- a special methodological to design user friendly products in the sense of providing user-product interfaces which constrain the user to only appropriate manipulations, the concept of affordances appears here too (Norman, 2002);
- attention with the co-operative versus individualistic approaches in different design tasks and design phases.

Ordinary devices are usually drafted by a single designer. However more complex utilities (e.g. cars, aircrafts, buildings) are designed in teams. Safety aspects (or other specify requirements) can be lost if there is no monitoring or evaluating in design phase reviews or in the project implementation.

The points above are of great value in all design phases: during the cabin safety test failure analysis and in the field problem analysis.

Another researcher in Human Error is Sydney Dekker, a Professor of human factors and system safety at Lund University in Sweden. In one of his several books and papers about this subject entitled The Field Guide to Human Error, he mentioned that when you are faced with a test failure that has a significant human contribution in it: What do you do? How do you make sense out of the controversial and puzzling assessments and actions by people? You basically have two options, and your choice determines the focus, questions, answers and ultimately the success of your probe, as well as the potential for progress on safety:

- You can see human error as the cause of trouble;
- You can see human error as the symptom of deeper trouble.

The first is called the *old view of human error*, while the second is the *new view of human error* (Dekker, 2001) – Table 2.2.

Table 2.2 – Human Error – Old and new view

The old view of human error	**The new view of human error**
Human error is a cause of accidents.	Human error is a symptom of trouble deeper inside a system.
To explain failure, you must seek failure.	To explain failure, do not try to find where people went wrong.
You must find people: inaccurate assessments, wrong decisions, bad judgments.	Instead, find how people's assessments and actions made sense at the time, given the circumstances that surrounded them.

Source: Sydney Dekker (2001).

During this research, working in the cabin safety team for interior certification of Embraer products, cabin safety test failures were witnessed. Considering Professor Sydney Dekker's theory about human error, the author agreed with him and indicated that there were two ways to move forward:

(i) consider the volunteer as the failure cause or (ii) assess deeply the human error to identify the symptom of the trouble. There is an immediate tendency to adopt the fast and easy way that is considering the human as the failure cause.

Our experience and literature review demonstrated that when appropriate time and resources are applied to perform a deep assessment of the failure, plus the introduction of psychological aspects brought by Bernhard Wilpert (mentioned above) and combined with the safety specialist's knowledge, the avenue for the success is being constructed. There is no magic procedure, or easy design process that will succeed all the time, however this conceptual methodological approach could bring better results.

To finalize this Section it is relevant to mentioned that "Human error" as an explanation for accidents has become increasingly an unsatisfying answer.

2.3 BIBLIOGRAFIC REVIEW AND RESEARCH ABOUT CABIN SAFETY

2.3.1 What draftsman and industrial designers should know about safety

Once an Executive Jet Program Manager mentioned "Designers are the most important player in aeronautical business". For the part numbers that s/he designs and calls out to be installed in the project, the rest of the business chain ought to do their best to have it incorporated in the aircraft. Based upon the practical experience of the author of this thesis, this is true for other reasons as well; designers shall comply with innumerous requirements.

During the development phase, it is possible to witness how requirements and creativity have an intense fight in the designer's brain. For the cabin safety designers, the product that they are designing will be used and operated by the most important person in the aircraft: the passengers (will all due respect to the pilots and flight crew). Besides customer requirements, attention shall be paid to safety requirements, as mentioned here. Crashworthiness shall allow passengers to abandon a cabin after a survivable accident. We could do a simple trade off to better understand this point. What we prefer is an extremely comfortable seat or a seat that will protect us during a crash. The evident answer is that we prefer both, therefore the daily dilemma for interior designers is this compliance with these two requirements.

During this research, as mentioned above, to increase safety in a cabin there are concepts that are needed to be monitored. These concepts shall be present in all project phases or design processes. Moreover, the safety designers and safety specialists are the ones considered highly responsible for this. It was also verified that there are research and programs dedicated to improve the attention paid to safety issues, but few addressing the safety designer's specialization. So the target here is to bring some light and debate about what designers should know about safety and understanding how designers have currently considered safety in their projects.

Andrew Hale ad hoc (Hale, 2007) has captured very well the anguish experienced in the cabin safety design office. He mentioned that a fundamental concern of the design process (and for cabin safety this is potentiated) is the issue of predicting and influencing the conditions and methods of handling and use of what is being designed. The designer needs to see his/her role not simply as designing safe hardware, but as designing safe use.

In the last years working on this research and also as a safety specialist at Embraer, the interface with the (interior) safety designer was intense and very rich. The knowledge generated during this period was significant and particularly interesting when we faced with a test failure with volunteers. The failure root cause analysis revealed that specific project details (sometimes a very tiny detail) not considered during the design process could be beneficial for volunteers to better understand and use aircraft safety features properly.

Here we see a particular characteristic of the interior designer being optimistic about risk control because they assume the passengers will follow their operating rules and their safety design features. It was identified that interior designers shall be trained and skilled with the knowledge about the intimate connection between interior design, human factors and affordance, in addition all aircraft interior projects shall take account of the trial (with volunteers) during its development, bring to design inputs from the error behavior, the differing individual expectations and the different volunteers behavior reaction.

Hale mentioned that to support designers in their task of incorporating safety into design, we must link in to the way designers think and work otherwise the transplant will be rejected. (Hale, 2007)

In particular, we must provide conditions to designers and amplify their views and knowledge of passengers behaviors during all flight phases, and familiarization with the situations that the passenger will use that specific feature that are being designed. Suggestions for this intent is to provide more insights regarding the strengths and weaknesses of human behavior in normal and emergency situations, appropriate case studies to implement in their design process, the affordance concept to better guide passengers to appropriately use safety features.

The conditions mentioned above would contribute to give the designers mental models they can use to test their designs against thought experiments, to supplement actual user trials and design reviews.

It is necessary to encourage all the engineers and designers responsible for the interior cabin project to think about safety from the start, even in the very early design phase.

The companies that design and produce Interior Cabins will be in a good situation regarding cabin safety when designers are not merely answering safety questions, but when they are themselves asking such questions.

2.3.2 Bibliographic review and research about cabin safety

The bibliographic review for this research has covered some specific segments. One special part was about Cabin Safety Design. In fact a bibliography specifically about aircraft cabin safety design it is not available, what is more abundant is about safety and safety related with design. For our thankfulness the Safety Science journal in 2007 released a special issue (volume) based on a workshop held by New Technology and Work series as described below (Safety Science 45, 2007):

- *This special issue is concerned with getting safety into design. This is a subject where we would like to address designers, as they are the only people who can ultimately take up its message and run with it. They are the people who have the skill and responsibility to make what they design as safe as is reasonably practicable. Yet this special issue contains papers largely written by safety specialists outside the design profession, who can at best analyze, assist, cajole, persuade and review those designs and that design process. This is a paradox which is at the heart of this subject area. Many of the papers are concerned centrally with the question of who can do what to make designs safer. We would like to make clear, right from the start that we have, as safety specialists, a great admiration for the job which so many designers now do in incorporating safety into their designs. But it is the task of the safety specialist to criticize and to want to achieve even higher goals. We see our task in this special issue as assisting designers to stand back from their work and see the processes they are operating in and how safety fits into them, and then to reengage in that work with the help of the knowledge, tools, and approaches which the papers offer. A secondary, but important audience is also the safety specialists working to assist designers. We hope they will learn, from seeing the approaches and pitfalls in other industries and technologies, how they can improve their support for design. Finally we address the researchers in the field. There are some considerable gaps in our knowledge of how to improve safety by design. In particular we know far too little about how designers tick. How do they think about safety, about use of their designs and about their influence on both of those? The final paper of the special issue reflects on those gaps in knowledge and tries to identify a research agenda.*

The workshop on which this special issue is based was one of the continuing series of workshops in the New Technology and Work (NeTWork) series, a long running scientific endeavor emerging from an international, interdisciplinary study group. NeTWork was originally sponsored by the Werner Reimers Foundation (Bad Homburg, Germany) and the Maison des Sciences de l'Homme (Paris). Since 2002, the role of the Werner Reimers Foundation has been taken over by other funding bodies such as the University of Eindhoven and the Dutch Ministry of Social Affairs and Employment. The workshop was attended by some 20 safety and design experts working in a range of industries, from oil and gas, chemical and process industries, to road, rail and air transport systems, and from manufacturing and product design, to space and medical systems. The editorial mentioned that the intention was to range broadly in this issue and try to specify generic principles and approaches, which help to see where one industry or activity can learn from the approaches of another. (Safety Science 45, 2007)

To locate my research with papers presented in this workshop a structure was compiled of the content of papers from the special issue and included my work at the end of the Table 2.3.

Table 2.3 – Structure and Contents of researched papers versus this research

AUTHORS	INDUSTRY ACTIVITY	PERSPECTIVE	ISSUES FOR DESIGNER	ISSUES FOR SAFETY SPECIALIST
Baran	General	Lawyer	Liability, legal incentive, duty	Liability
Kinnersley and Roelen Taylor	Air traffic control, rail nuclear Process	System Safety	Safety motivation	Leverage, arguments from error prevention
Taylor	Process	Designer	Statistics of design error. Current success and remaining challenges	Leverage, arguments from error prevention
Taylor	Process	Designer	Role in total design process. How safety fits in the design process	Myth and reality in design. Insight into error causation
Kjelle´n	Oil and Gas	Safety/HF specialist in the design team	Normative approach to safety in design link to capital value process	Role of safety experts and designers balance between safety barrier and human factors
Droghoul et al.	Software	System safety	Generic and specific design approaches to software development	Opportunities for cross fertilization between industries
Kirwan	Air traffic control	Safety specialist	Systematic safety in early design	Place of safety in R&D

AUTHORS	INDUSTRY ACTIVITY	PERSPECTIVE	ISSUES FOR DESIGNER	ISSUES FOR SAFETY SPECIALIST
Fadier and De la Garcia	Printing presses	Safety specialist	Limitations of standards. Drifts from design to use	Need for design support. Managing life cycle of equipment
Jagtman and Hale	Road Trafic	Safety specialist	Limitations of standards. Designers can influence unintended use	Adapting approaches from other industries
v. Duijne et al. de Mol	Consumer product	User designer	Value of user information. Creativity and safety	Communicating with designers
de Mol	Medical devices	Safety specialist, user	Challenge of new application Need for structure	Innovation vs. risk control cost- benefit
Wilpert	General	Psychologist	Transparency of design process. What goes on in my head?	Communicating with designers in their own terms
Hale, Kiran and Kjellen	General	Safety specialists	Overview of problems and ways forward	Research agenda
Silva, Cesar Alberto	***Aircraft Manufacturer***	***Cabin Safety Specialist***	***Identify and translate airworthiness requirement into design aspects***	***Introduce a Design for Cabin Safety method to increase the adherence of safety requirements into design***

Source: Author (2019).

The 1990s would point to the need to integrate cross-functional work on a large scale, given the complexity of the issues inherent in the product development, giving shape to the concept of integrated product development, based on collaborative work (CUNHA, 2008). In this scenario, the objective of integrated product development is linked to the reduction of product development process time through the integration of work teams, allowing organized parallelism between the product development process phases (ROZENFELD et al., 2006).

2.4 SUMMARY

This chapter has brought the scenario by which Cabin Safety is inserted in the aeronautics context and the intrinsic relationship between ergonomic and cabin safety and ultimately how the airworthiness requirements try to capture these aspects to compose a crashworthiness configuration.

Very few accidents are associated with a single cause. The causes of accidents are usually complex and interactive. Cabin Safety specialists know that seconds are relevant for evacuation. Small design details may provide clearance to cross the cabin. Simple features can protect passengers and crew. Static and dynamic tests on seats may find weak and strong points that will either not protect or protect the passenger. Furthermore, well-defined procedures with appropriated placards can lead the passengers to evacuate the aircraft safe and healthy after a survivable aeronautical accident.

The research in aeronautical accidents, safety regulations, interior cabin safety features and human factors results in the identification of opportunities for new cabin interior approaches to enhance safety in aviation. Safety regulations applied in cabin safety solutions shall be developed, tested and validated with a robust comprehension of the human factors.

“Flying safely and accident survivability is not a miracle, but regulations based on solid research is what made it possible!" (Morin, 2007).

Next chapter introduce a method adopted to convey what this theoretical foundations chapter has introduced and described.

3 DESIGN FOR CABIN SAFETY METHOD

Chapter 2 has presented the theoretical referential framework about Cabin Safety and associated works related with this subject and the requirements considered for this technology. The objective of this chapter is the formulation, construction and development of the method.

Specifically this method aims to integrate the requirements of Cabin Safety into the conceptual phase of the aircraft interior design. The final result is a method of assessment and translation of the standard configuration (initial configuration) into a safety configuration, labeled as ***Design for Cabin Safety (DF_CS)***.

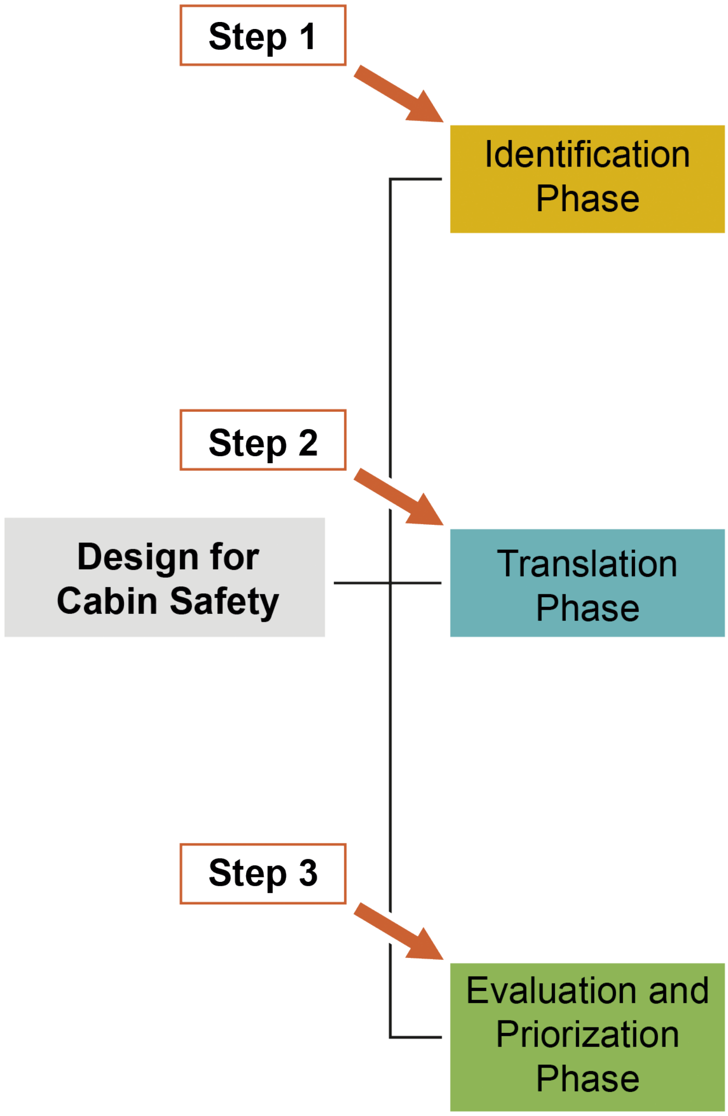
DF_CS – Conceptual Framework Diagram

The proposed method aims to tackle one of the challenges of this technology (Cabin Safety) that is lowering the subjectivity of its requirements translating them into the design language. With that intent it is necessary to consider airworthiness and crashworthiness requirements, conditions and environments to test the project, human factors aspects and user-friendly design conception (affordance concept).

It is relevant to mention here that aeronautical requirements can be released as *prescriptive requirements* (for ex. the passenger aisle width at any point between seats must equal or exceed 20 inches) or *performance-based requirements* (for example: hand fire extinguishers must be "conveniently located"). In the sentence above, where it is mentioned that cabin safety requirements are subjective is because much of the Cabin Safety requirements are performance based requirements like the example about hand fire extinguishers. Where what is "conveniently located" for one designer could not be for the regulator authority inspector. There are pros and cons for both kinds of requirements. Prescriptive ones are clearly defined and demonstrations are well established. However they is less flexibility in the compliance. Performance based requirements are more flexible allowing each aircraft manufacture to have its own cabin configuration to a specific certifiable design. However compliance findings will vary according to the personal opinion of the regulatory authority inspector.

The method has 3 main steps as illustrated in the Conceptual Framework Diagram in Figure 9.

Figure 9 - DF_CS Conceptual Framework Diagram



Source: Author (2018).

Before detailing the steps of the method, it is worth presenting the premises adopted by the author for developing the proposed method. The method herein developed has its foundations in Concurrence Engineering for Integrated Product Development, specifically in the Design for Excellence methodology, summarized as follows.

3.1 DESIGN FOR EXCELENCE - DFX (METHODOLOGY FOUNDATION FOR DF_CS)

As posed in Chapter 2, to design a feature or system adherent to Cabin Safety, it is necessary to consider different variables: crashworthiness requirements, human factors requirements, ergonomic aspects and user affordance. In North America, the study of Human Factors initiatives tends to have a bias founded in psychology. In Europe, the term used to describe the study of Human Factors has been “ergonomics”, which traditionally has a bias towards the biomechanical and biophysical aspects of work. Today, the terms Human Factors and ergonomics can be used interchangeably. Both imply consideration of all the factors that affect human performance in the workplace (ICAO, 2002). Furthermore, in addition to capture safety via design – that ultimately would improve the survivability – the goal is to determine which operational training for the crew would bring better results in emergency situations. All these analyses and researches converge to the ultimate goal of this work that is to find a new cabin safety methodological approach to improve survivability.

As this research was carried out in conjugation with experimental observation of the aircraft interior development and its certification process, it has been possible to evaluate different methodological approaches (described in Chapter 1) such as the FAA research about separate areas of the cabin interior and the safety science community researches about the design process, the design phases, and the designer’s abilities and competencies, etc. From the time when this research began, the objective was to collect lessons learned from different Cabin Safety design conceptions and from different Cabin Safety tests using volunteers and elaborate a catalog of explanation and test procedures to guide designers and cabin safety specialists in new projects. When this author had contact with the methodology called Design for Excellence, it was observed that the possibility and the potential of this methodology to address this research goal was achievable and, then this project was influenced and moved in this direction.

The contents of the Design for Excellence (DFX) methodology brought a different perspective to this work development. It has been observed in the DFX that an appropriate approach to design through a systematic procedure could guide and assist designers and cabin safety specialists to evaluate a new standard interior configuration and translate that into a design that will result in a safer interior configuration. In addition DFX method are related with integrated product development. A new aircraft program development need to integrate cross-functional work on a large scale, given to the complexity of the issues inherent in this product development. Some aircraft manufactures adopt the the concept of integrated product development, based on collaborative work.

A great number of Design for X methods were developed and are available to promote the integration of different technical areas of product development, such as Design for Manufacturing (DFM), Design for Assembly (DFA), Design for Recycling (DFR), Design for Service (DFS), Design for Automation (DFAut) and so forth. All of these DFX (Design for X or eXcellence) methods have in common the aim to integrate the requirements of the technical area X into the conceptual design phase of the product.

The technical area (X) of the DF_CS is *Survivability* i.e. the capability of the passenger/crew to survive in a minor crash and afterwards be able to unbuckle their safety belt s, stand up from their seat and leave the airplane following the internal markings and emergency lighting via the main door or over wing exit and reach the ground safely. Following the general framework of the DFX, the method detailed herein is formulated, constructed, developed and implemented based on traditional design guidelines and rules derived from the merge of the lessons learned experience from cabin designers and cabin safety specialist.

The Design for Cabin Safety (DF_CS) method does not make design decisions. Instead, it assists the design team to decide on design options from a specific point of view, namely, survivability. The method aims to integrate cabin safety requirements into the aircraft interior design solutions.

3.1.1 Introduction to constitutive steps of the DF_CS method:

S***tep 1*** of the method is to identify which requirements are involved in a new configuration or affected by the change in a specific interior previously designed and implemented in the aircraft. For this purpose, besides the airworthiness requirements, other aspects ought to be considered guiding the DF_CS user in the next stages. The identification of the requirements and survival aspects involved in the configuration shall be integrated to result in an safe design.

Most of the Cabin Safety requirements are not written in a prescriptive way providing parameters, dimensions, formats etc. to design and build the solution that complies with a specific requirement. On the contrary the requirements are subjective (performance-based requirement) providing the general idea that the designs shall have to demonstrate, as exemplified below:

- ✓ need to ensure <free access>;
- ✓ use must be <simple and obvious>;
- ✓ operation should not require <significant effort>;
- ✓ the instruction must be <conspicuously placed>.

This is why this method was introduced as a step to translate the subjective requirement semantics into requirements for the project.

The current process to analyze these requirements and its subjectivity without a proper method are based on lessons learned from the design team created on previous developments.

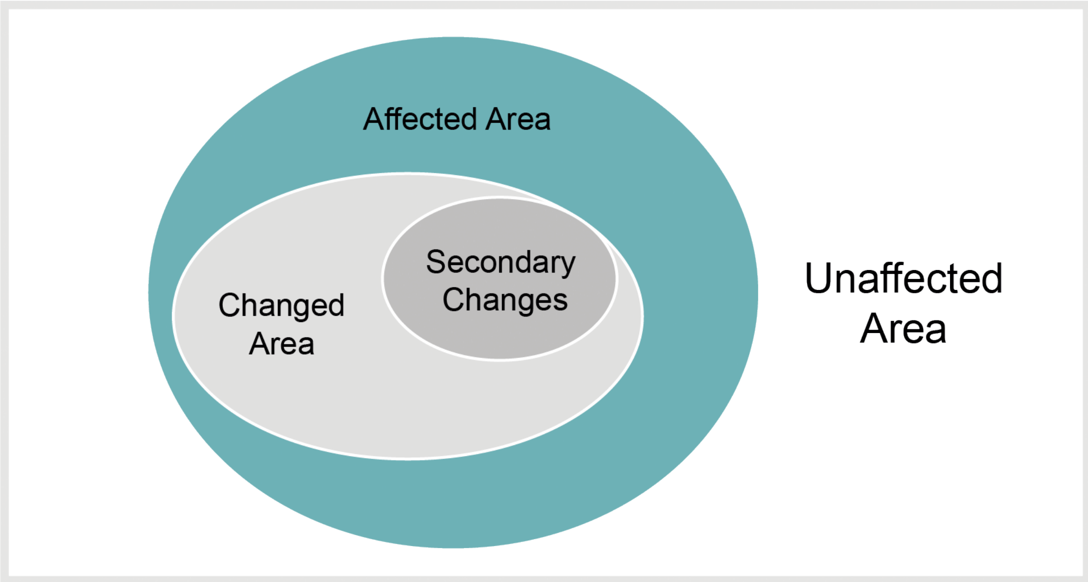
The final configuration considered for the change or for the new configuration may face with restrictions before being implemented. Thus the assessment regarding survival aspects and affordance may contribute to make these requirements properly understood and discussed in an Integrated Product Development technical meeting.

The <other relevant items> in this step are related to the configuration to which the component will be installed, the environment that the component will be maneuvered in, the human factor aspects and the usability (affordance) of the equipment.

Another important concept that is relevant and ought to be considered in the requirements integration for new cabin design is related to the “changed area”. A change in a specific portion of the interior may affect some areas and not affect others (Figure 10). For example, if you are changing a seat back by installing a tray table plus an IFE system and this seat is positioned immediately in front of the over wing emergency exit, the change will affect the area. Because in this area, (OWE) the access must be provided an unobstructed passageway.

Minor changes in aircraft cabins where the final users are human beings may affect other areas altering the change classification to a major change with impact to the passenger behavior during emergency conditions, evacuation, crew procedures etc. The Figure 10 idea is to introduce the designer to this concept, that a change in a specific item may affect the whole area where the item is installed.

Figure 10 - Change Procedure Rule for Affected and Unaffected Area



Source: EASA Easy Access Rules for Airworthiness Certification Part 21 (2018).

Step 1 summary:

Inputs: Standard Configuration;

Techniques: Identification and Parameterization of the Components with Requirements.

Outputs: Parameterized components and integration

Once the components and its associated requirements are identified, and the integration among them was evaluated, it is necessary to translate that into interior project language in ***Step 2***. The term “translate” denotes the action to evaluate the airworthiness requirement body language and evaluate in what way will the unfolding of this requirements be in terms of the product design. The American Heritage Dictionary among others definitions for translate states the following: “translate = to express in another medium” thus the Step 2 of this method will do this. In addition, one airworthiness requirement could be unfolded into more than one design requirement.

Each of us that has hired an architecture to build a house, or have ordered furniture from a carpenter, or have ordered a flower bouquet from a florist ought to give these professionals our requirements regarding the final product format or characteristics that we would like to see incorporated in the final product. Thus these professionals ought to *translate* our requirements into a desirable final product.

In this step of the DF_CS method, the task is that the cabin safety requirements are translated into an interior product that final users, e.g. passengers and crew, will be able to properly use and protect themselves in any flight phase, during normal and emergency situations.

The requirement examples stated in Step 1 describe as <simple and obvious>, as previous mentioned in this work, is extracted from the requirement applicable for emergency exit door. Thus the interior design in this step shall translate simple and obvious in project characteristics (i.e. shape and format) that equips the door aperture mechanism design with an easy interpretability language and signals (affordance) allowing user to operate the door properly, i.e. without previous knowledge how to open the door and through its placards how to escape from the aircraft interior.

These translations in this research are based on lessons learned and ought to be updated by the method's users.

There is no specific tool for this translation similar to tools like *Google Translator*. And is not a simple task based on the opinion of one user or designer. It demands dedicated work to reach good results along with some trials/tests. In the book Constructionism in Practice - Design Thinking, and Learning in a Digital World – (Resnick, 1996), the author mentioned the designer Donald Norman here mentioned in the Chapter 1, in the chapter *Natural Mappings and Feedback.* Norman argued that the primary source of problems with designed things is that there is a gap between the designer and the user of designed objects: Norman attributes these difficulties to (a) unnatural mapping between mental and physical states and (b) inadequate feedback of the effects of user actions. It is quoted that Natural mappings take "advantage of physical analogies and cultural standards", where he brings again the examples of the doorknobs (Figure 8) where a small rectangular plate invites the user to PUSH, whereas a narrow protruding bar invites the user to PULL to open the door. The other point that contributes to the translation challenge is the concept "the difficulty of dealing with novel situations is directly related to the number of possibilities". An example that is easy to demonstrate is regarding the requirement <easy to access>. It is translated to project requirements as: <to easy access a specific device it is not necessary to move anything in front of it >.

Step 2 summary:

Inputs: Parameterized components and integration

Techniques: Operate the semantic translator such that from the safety aspects one can translate to the safety design

Outputs: Safety Design

Fundamental attributes for any decision-making process is the ability to quantitatively or qualitatively assess and analyze applicable requirements that drive product development and its final design conception characteristics. ***Step 3*** is built with this intent.

Since the requirements were identified in step 1, translated in step 2, in this step the following tasks ought to be performed:

- product design evaluation <this evaluation ought to be a design review or a real test simulation in the aircraft or mockup environment with volunteers>.
- prioritization/definition about which aspects will be implemented in the final product. Afterwards in order to evaluate the new project's use, the interior design team (or the IPD) needs to select which are the design characteristics (among all identified) that will or not be implemented in the final project. These two tasks is detailed in chapter 3.2.3 and demonstrated in chapter 4.

The method developed in this work contributes with this qualitative assessment in the designed interior configuration and also contributes to its implementation, based on the analyses of the applicable requirements and derived solutions.

Step 3 summary:

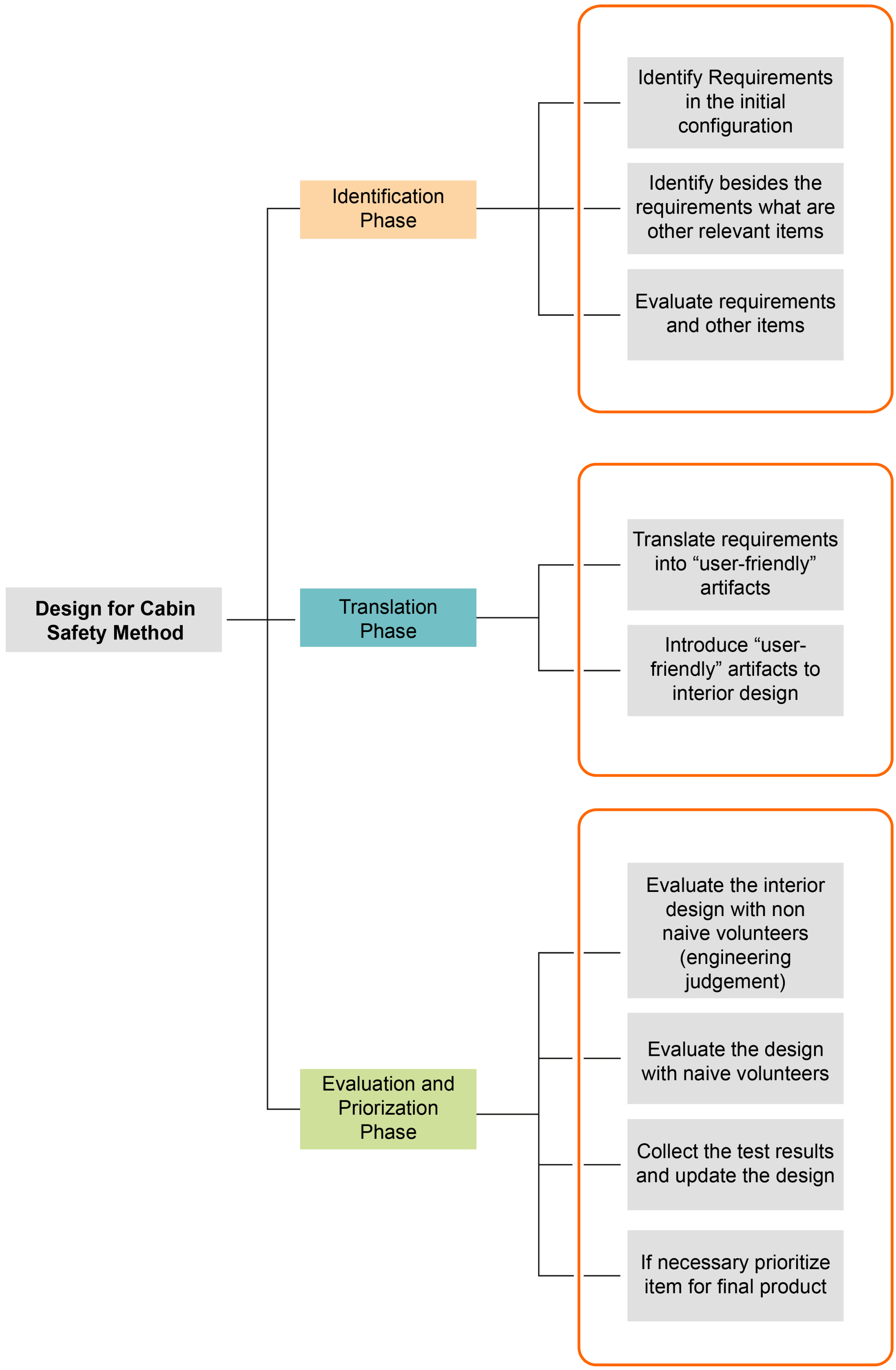
Inputs: Safety Design

Techniques: evaluation thru design review or real test simulation and prioritization according to the data collected in the test.

Outputs: Safety Configuration

The constitutive three steps, as above described, included in the Conceptual Framework diagram shown in Figure 9 have individual tasks with specific goals as depicted in the roadmap of Figure 11.

Figure 11 - Design for Cabin Safety Method Roadmap



Source: Author (2018).

3.2 DESIGN FOR CABIN SAFETY METHOD DESCRIPTION (DF_CS)

Here is where we start the DF_CS method-description for the task of mapping a knowledge for this method's users and for future amendments.

Concurrent Engineering (CE) is an ideal environment for product development. Among others, its objective includes improving quality, reducing costs, compressing cycle times, and increasing flexibility and efficiency. The ways of achieving these objectives is through cooperative teamwork between multiple disciplinary functions during all design processes.

According to literature review, Design for X is one of the most effective approaches to implement CE. In summary the book (Prasad, 1996) quotes:

What does a DFX method do?

1. Gather and present facts about products and process;
2. Clarify and analyze relationships between products and process;
3. Measure performance;
4. Highlight strengths and weaknesses and compare alternatives;
5. Diagnose why an area is strong or weak;
6. Provide redesign advice on how a design can be improved;
7. Predicts what-if effects;
8. Carry out improvements;
9. Allow interaction to take place.

The above observations were considered in the DF_CS method development.

Using each X technology, the method guides the user to focus on a limited number of variables, approximately 7±2, of vital elements (primary factors) at a time.

As mentioned before, **X** in DFX stands for manufacturability, recyclability, assembly etc. These words are made up of two parts: life cycle business process (x) and performance measures (bility) that is,

X = x + bility

DESIGN FOR SURVIVABILITY

For example, <x=total> and <bility=quality> in <design for total quality>.

For the proposed DF_CS method, <x=design (with affordance)> and <bility=survivability> so <design for survivability> that represents the main objective of Cabin Safety. Thus this is what Design for Cabin Safety stands for.

Following the structuring steps of the generic Design for X methods, the primary factors were identified among airworthiness requirements applicable for Cabin Safety (Table 1).

As shown in Chapter 2 - Table 1, the requirements are grouped in sub-parts or cabin aspects like <Fire Protection>, < Emergency Provisions >, < Safety Equipment > etc. In this research based on the author's experience, accident investigation (Silva, 2013) and regulators's concerns (Silva, 2013) there were four areas identified as primary factors for DF_CS considering the significance of these factors/requirements to improve survivability in the cabin design, these factors are listed in Table 3.1.

Table 3.1 – FAR PART 25 – Sub-Part D – Design and Construction

SUB-PART D - DESIGN AND CONSTRUCTION
Personnel and Cargo Accommodations
Emergency Provisions
Safety Equipment
Marking and Placards

Source: Author (2018).

The factors listed in Table 3.1 are composed of particular requirements that are presented in Table 3.2:

Table 3.2 – Primary Factors for Safety Aspects (FAR PART 25)

SUB-PARTS	REQUIREMENTS	Requirement Number (§)
Personnel and Cargo Accommodations	1 - Seat must be designed so that a person making proper use of these facilities will not suffer serious injury in an emergency landing.	§ 25.785
	2 – Stowage compartments that retain the items of mass in passenger and crew compartments and galleys.	§ 25.787/789
	3 - Passenger information signs and placards.	§ 25.791
	4 – Floor Surfaces must have slip resistant properties.	§ 25.793
Emergency Provisions	5 – Exits and emergency exits must be signalized, illuminated, may not require exceptional effort to be operated and it operation shall be simply and obvious.	§ 25.803 / 807 / 809 /810 /811 / 812/ 813 / 820
	6 – Width of aisle and maximum number of seats abreast.	§ 25.815 / 817
Safety Equipment	7 – Emergency equipment must be readily accessible, its location must obvious and its stowage be conspicuously marked.	§ 25.1411 / 1561
Marking and Placards	8 – Cabin must contain markings and placards (for safe operation) and each marking and placard must be displayed in a conspicuous place.	§ 25.1541

Source: Author (2018).

Design for Cabin Safety STEPS

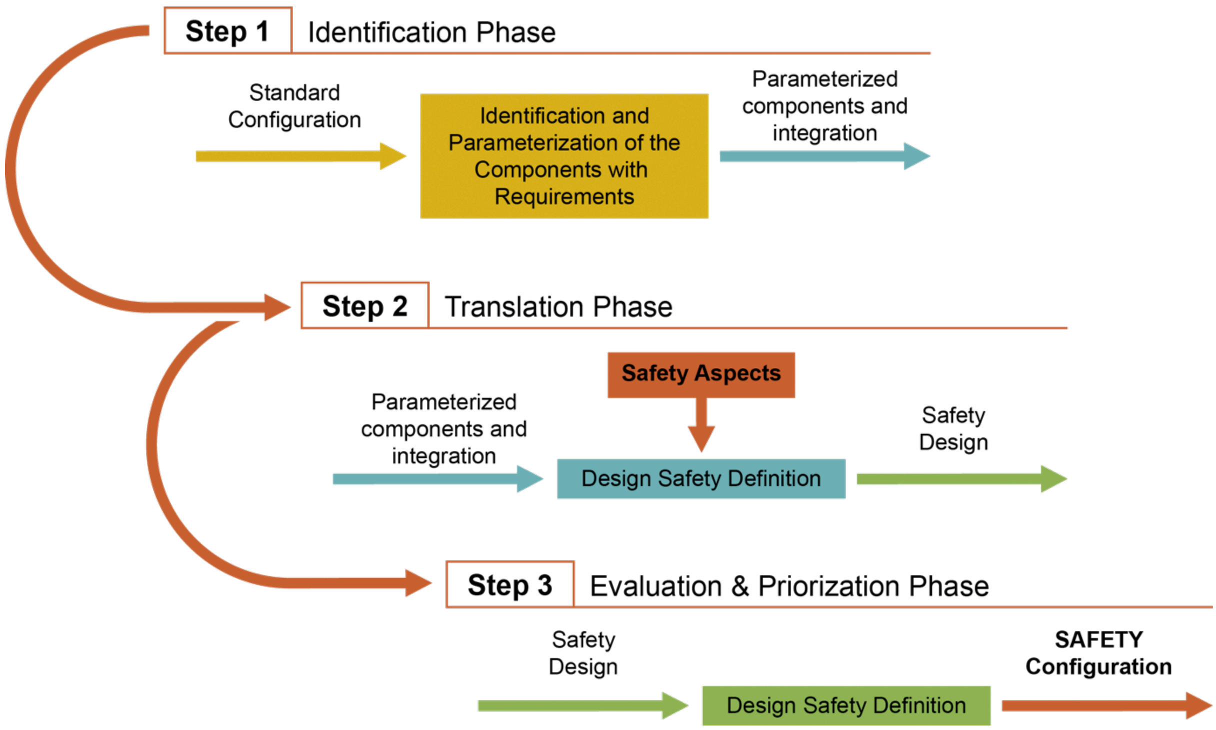
Design for Cabin Safety method, has similarity in steps with other DFX methods, differing with the goals. In addition, each steps is split up into tasks.

The generic steps are:

- ***Step 1***: Identification Phase => *Identification and parameterization of the component with the requirements;*
- ***Step 2***: Translation Phase => *Design Safety definition*;
- ***Step 3***: Evaluation and Prioritization Phase => *Safety configuration definition.*

as shown in Figure 12 and detailed as follows.

Figure 12 - A three-step Design for Cabin Safety method



Source: Author (2019).

3.2.1 STEP 1: identification phase => identification and parameterization of the component with the requirements

In this step, the method user shall identify which are the components of its modification and verify if there are requirements associated with this component.

As described in Chapter 2, each feature or system that is installed in a cabin interior configuration shall comply with one or more airworthiness requirements. Each requirement is written to bring a specific characteristic that contributes to a portion of the safety that is necessary to be present in any aircraft interior cabin.

The approach to address the requirement identification and then interface and parameterize ought to be extracted from the requirement text first.

For example:

i) Markings and Placards that are installed in an aircraft cabin must be displayed in a conspicuously place and may not be easily erased, disfigured, or obscured.

ii) Safety Equipment:

(a) Accessibility. Required safety equipment to be used by the crew in an emergency must be readily accessible.

(b) Stowage provisions. Stowage provisions for required emergency equipment must be furnished and must — (1) Be arranged so that the equipment is directly accessible and its location is obvious; and (2) Protect the safety equipment from inadvertent damage.

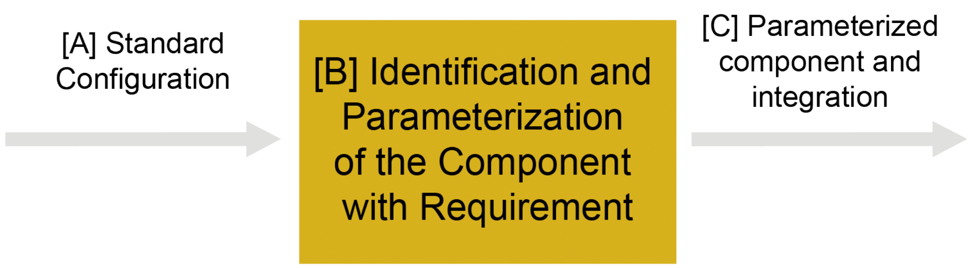
Thus, the installation shall prevent the equipment from being hidden by other articles placed in a compartment or stowed near the equipment. The compartment design shall prevent emergency equipment from being damaged by other articles stowed in the same compartment. Each item of safety equipment to be used by the crew must be removed independently of any other equipment stowed in a compartment and without damage. All safety equipment required to be used by the crew must be readily and directly accessible (not requiring special skills to remove), and located in an obvious location.

Some other equipment such as a megaphone must be demonstrated to be accessible within five seconds by a fifth percentile flight attendant in the nearest flight attendant seat. These examples demonstrate how the interface that an interior component (e.g. emergency equipment) ought to be with the interior configuration and how the cabin safety specialist shall build the parameterization.

Thus, at this first DF_CS step, the input for the method is a set of specific interior component (planned to be designed) that is analyzed and parameterized.

The output for this DF_CS step is the components analysis regarding which safety aspects need to be captured for a specific new configuration (full-size project) or design change (small project). Step 1 is illustrated in Figure13.

Figure 13 - Step 1. Identification and parameterization



Source: Author (2018).

[A] The labeled input “Standard Configuration” is the interior configuration component with enough details and expectations regarding what is the proper use that the passengers ought to perform using this (new) device (or component) or procedure providing clues for the next step that is to associate this components with the specific crashworthiness requirement.

[B] Knowing interior configuration components (design details and required affordance) this point will attribute parameters (derivate from the requirements) that components must comply with.

[C] The “Parameterized components and integration” output is a clear definition regarding which components composed the design change or new interior configuration with respective requirements and characteristics that must be complied.

3.2.1.1 Factors influencing behavioral responses to emergencies

As mentioned before, DF_CS method is based on the methodology of Design for Excellence (DFX) combined with the lessons learned from the author’s experience as a cabin safety specialist. This combination generates the perception to introduce in this method what is labeled in the literature review as Factors Influencing Survival (Wilson, 2008). Prior to describing these factors, it is relevant to mention that they are related with test procedures to demonstrate design compliance with the requirements. Thus, they ought to be considered during the design phase. As introduced with Norman (2002), the challenge with design is the options offered to the final user when the device designed will be used the first time. Thus, the designer shall have to consider that a naïve passenger in an emergency situation doesn’t have much time or the particular knowledge to make a decision. So, don’t create a design conception that allows them to diverge from the main purpose the feature offers. Just to illustrate, if the project is a door, allow them at first glance to be sure that the doorknob is to push not to pull or otherwise.

Rebecca mentioned in the Symposium <Outlook on Safety> in the paper: *Man and Machine: systems for safety* the human factors SHEL model as a means of explaining the different components of a system and the interactions between these components within the aviation domain (Edward, 1972). The DF_CS method is also looking for the interactions between the interior components and its final user that is the passengers.

The SHEL model has then been used as a means of identifying the factors that may influence passenger survival in the event of an emergency. The model highlights four main components – **s**oftware, **h**ardware, **e**nvironment and **l**iveware. However consideration should not just be given to the components in isolation but also in combination, as interactions in the components will occur. This insight regarding <interior components should not be considered in isolation but in combination>, it was observed by this thesis author during some test fails for cabin safety interiors. In Chapter 4 this is discussed in further detail.

The work of Snow et al (1970) identified several factors that influence occupant survival during an emergency evacuation of an aircraft. Thus, there were a correlation elaborated with the SHEL model where Snow et al placed the factors into one of four categories – configurational (Hardware), procedural (Software), environmental (Environment) and biobehavioral (Liveware) as shown in Table 3.3.

In addition to the interior configurational factors, procedural factors, biobehavioral passenger factors and the environmental conditions, in the lecture "*In Times of Crisis how do Passengers React*" Muir suggests that crashworthiness and fire protection and evacuation aids also influence passenger survival in aviation accidents (Muir, 2004).

Based on the above-mentioned study about Factors Influencing Survival it was slightly derivated from it and introduced in Step 1 of the DF_CS the analysis of the following factors to verify whether any of these factors ought to be considered or not in the configuration component to be parameterized:

- ✓ the configuration to which the component will be incorporated for use by the passenger;
- ✓ the environment / situation that the component will be used (such as normal situation, emergency situation, with / without smoke, with normal cabin light or emergency lighting);
- ✓ human behavior that considers biological, psychological and cultural attributes of the individual as a passenger;
- ✓ the usability (affordance) of the equipment.

Table 3.3 – Factors Influencing Survival

Category	Description
Configurational	Configurational factors are the 'standard features of [the] occupant environment controlling access to exits and evacuation flow rates' Examples include the aisle width and the number, type and location of the exits.
Procedural	Procedural factors are the 'regulatory and training practices of crew and other non-passenger rescue personnel which influence evacuation procedures.' Examples include the cabin crew training and the standard operating/emergency procedures of the airline.
Environmental	Environmental factors are the 'features of the occupant space and outside the aircraft which control survivability and evacuation time.' Examples include the presence of fire and smoke, the level of lighting and the weather outside the aircraft.
Biobehavioural	Biobehavioural factors are the 'biological, psychological and cultural attributes of individual passengers which influence agility and behavior.' Examples include the sex, age and fitness level of the passengers.

Source: Rebbeca Wilson (2008).

3.2.2 STEP 2: translation phase => safety definition

Once the interior components, the applicable airworthiness requirement and the involved Factors Influencing Behavioral responses to emergencies are known at step 1, the method continues with the specification of the Safety definition (Safety D). Each airworthiness requirement (considering in addition the factors in the Table 3.3) for interior engineering introduces a subliminal safety arrangement in its normative text that ought to be translated into design requirements.

The Safety D is the key performance extracted from the airworthiness requirement that the interior component shall be compliant with. In this step, Safety D ought to be translated and unfolded in the generic design requirement(s) for the designer in a didactic way.

<u>Safety D and Semantic Translator – Crashworthiness to design requirements</u>

In Chapter 2 – Table 1 the requirements were referenced on which *Safety Equipment* shall be compliant with. To illustrate the concept of the Safety D semantic translation adopted in the DF_CS method let's analyze in detail the requirement language:

> *§25.1411- Safety Equipment*
>
> *(a) Accessibility. Required safety equipment to be used by the crew in an emergency* ***must be readily accessible****.*
>
> *(b) Stowage provisions. Stowage provisions for required emergency equipment must be furnished and must—*
>
> > *(1) be arranged so that the equipment is* ***directly accessible*** *and its* ***location is obvious****; and*
> >
> > *(2) protect the safety equipment from inadvertent damage.*

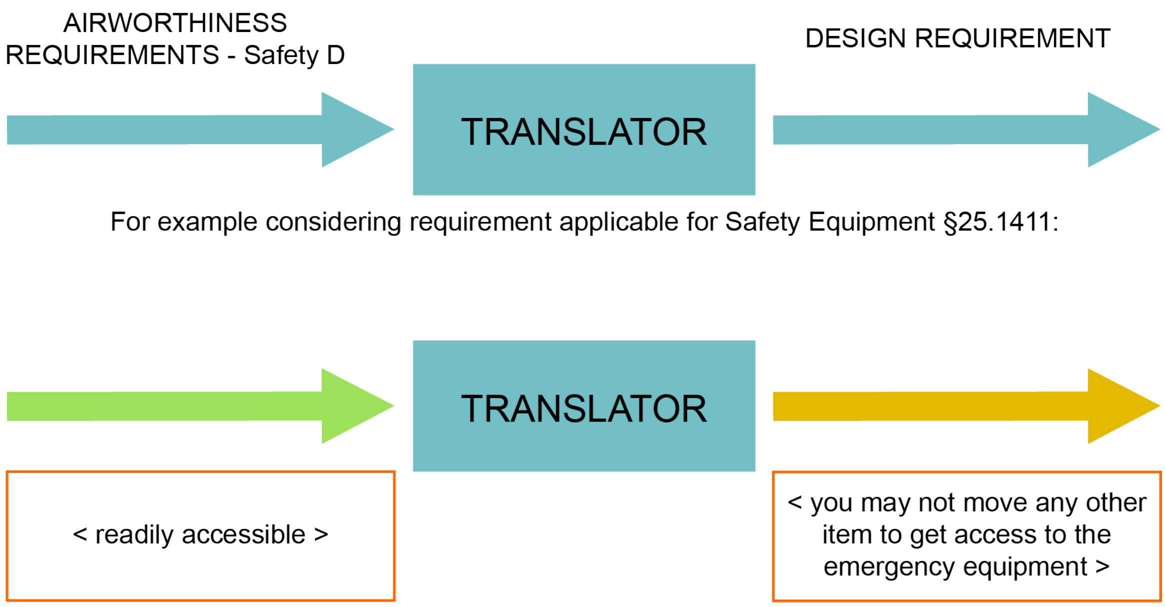
The requirements body of language:

- ✓ must be <readily accessible>;
- ✓ arranged as <directly accessible>;
- ✓ positioned in an<obvious location>;
- ✓ <protected from damage>;

are the *properties* that the designer ought to be focused to be adherent with safety in their project. Furthermore, if the design conception of the new product has these properties, it increases the chances that the performance-based expected from that specific design is be demonstrated.

The semantic translator has the function to translate these *properties* inputs in an output *feature, i.e.* to access safety equipment <you may not move any other item to get its access>. This Safety D translation process illustrated in Figure 14:

Figure 14 - Semantic Translator – Crashworthiness to design requirements



Source: Author (2018).

Table 3.4 includes other cabin safety components present in the requirements that shall comply with safety aspects (here explicit betwenn <__>). These requirements are items to be translated with safety definitions (SafetyD) as exemplified below:

Table 3.4 – Safety Guidelines

Cabin Safety Component	SafetyD
Placards	<conspicuously placed>
Emergency Equipment	<marked to be readily located and operated>
Safety Equipment	< easily removed>and <easily stowed after use>
Protective breathing equipment	< located within 3 feet of each required hand fire extinguisher>
Megaphone	< accessible within five seconds by a fifth percentile flight attendant in the nearest flight attendant seat >
Curtains	<free entry>
Lavatory Door	<unlock without special tool>
Crew Safety Equipment	< readily and directly accessible> and <not requiring special skills to remove>, and <positioned in an obvious location>
Hand fire extinguishers	< conveniently located> and, when two or more are required, <uniformly distributed throughout each compartment>
Over wing Exit	<simply and obvious operation> and <may not require exceptional effort to operate>
Main door	< may not require exceptional effort to operate>

Source: Author (2018).

The approach to properly "operate" the translator semantic engine represented in Figure 14 is to use the follow questions for each requirement identified in Step 1:

- ✓ What do you mean by <Safety D>?;
- ✓ Why is the <Safety D> needed?;
- ✓ What are the goals of <Safety D>?
- ✓ How to achieve <Safety D>?

For example, if the designer is tasked with a project to install a new lavatory door and according to Table 3.4 the Safety D for this door is to <unlock without special tool>, so the DF_CS method user shall address and answer the following questions:

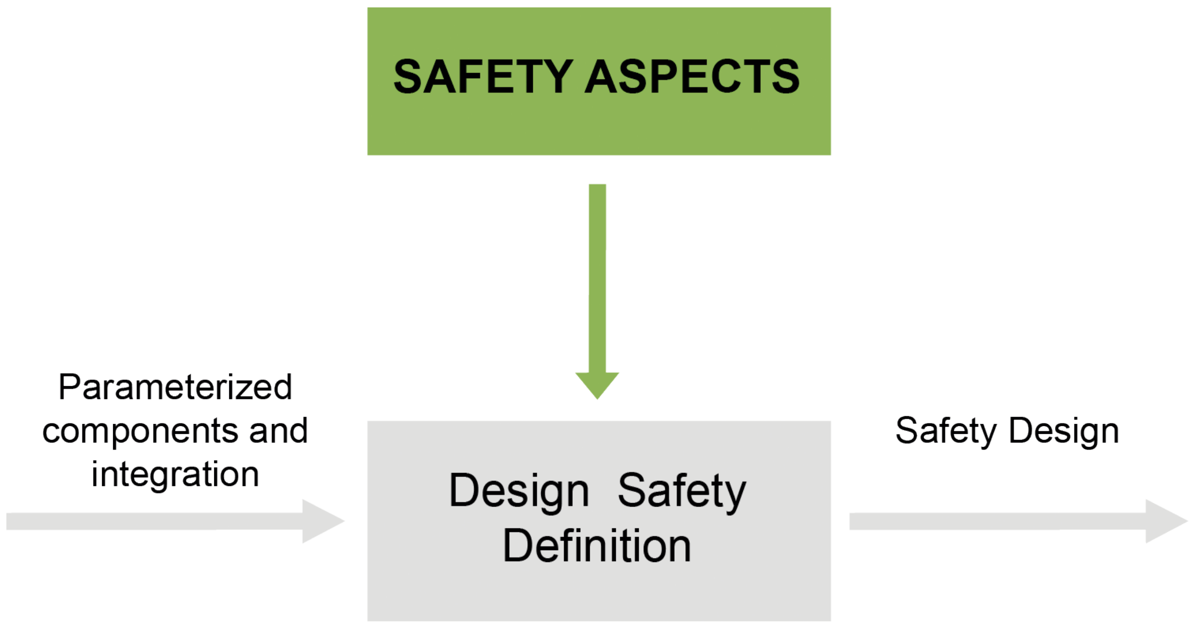
- ✓ What do you mean by < unlock without special tool >?
- ✓ Why is the < unlock without special tool > needed?

- ✓ What are the goals of < unlock without special tool D>?
- ✓ How to achieve < unlock without special tool >?

The exercise to answer the above questions forces designer to elaborate the design requirement.

At this stage, the interior design and the cabin safety specialists should evaluate previous products and processes to identify opportunities to improve user comprehension in features and procedures to be introduced in the cabin. The safety guidelines (Table 3.4) could be constantly updated with analysis performed in this step depicted in Figure 15.

Figure 15 - Step 2 – Design Safety Definition



Source: Author (2018).

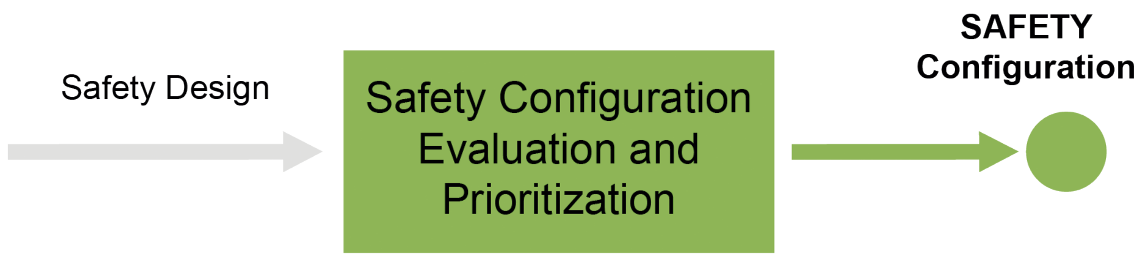
3.2.3 STEP 3: evaluation and prioritization phase => *safety configuration definition*

After the interior components the applicable airworthiness requirement and the involved factors influencing behavioral responses to emergencies are known at step 1 and the Safety Aspects (Safety D) recognized in step 2, the design team along with the safety specialist can construct the Safety configuration definition that is the step 3 objective (Figure 16).

The number of variables in the safety configuration depends on the magnitude of each modification or new project. In interior engineering there are projects that encompass a complete new interior configuration, or a design change that just affects a cabin portion or could even change only one component (its part number or its relative position in the aircraft). The size of the modification may dictate how many elements will compose the Safety Configuration.

Considering that the development of a new interior configuration or modification takes place in an environment of integrated product development, interior professionals should, within the configuration, evaluate if there are characteristics of the configuration components that deserve to be prioritized. It has to be said that when it comes to safety everything should be priority. But there are some project details that can make implementation more difficult or more expensive, so step two of the method has already contributed by making an adequate translation of the requirement for the project. Regarding the approach to assigning priorities, the IPD should seek a prioritization with the interior team in order to achieve the objective or set of objectives maximizing the main concept of Cabin Safety, which is survivability. The format to evaluate the configuration components is demonstrated in Chapter 4.

Figure 16 - Step 3 - Safety Configuration Definition



Source: Author (2018).

Similar DFX methods usually have some metrics with a respective index on which performance could be measured to guide the design team decisions. If was decided to do this in this work, it should attribute a value of survivability for each component identified in steps 1 and 2 use this value to decide which component(s) should be considered here in the step 3. Therefore, in this research, as it is understand that design details could contribute substantially and sometimes little for the product to be properly used, was chosed to plot in a matrix all translated and unfolded project items (derived from the requirements) and let the experience of interior engineering with IPD members define which items will or will not be implemented in the final configuration.

Thus, the step 3 method was designed to plot in a table or matrix the configuration set of components combined with its parameters plus its Safety Aspects (Safety D) and based on this big picture of the configuration to evaluate which of them will be implemented in the Safety Configuration (Chapter 4 - Table 4.3).

3.3 SUMMARY

As proposed, this chapter presented how the Design for Cabin Safety Method (DF_CS) was conceived, designed and created based on DFX methodology. Our method intends to integrate the requirements of Cabin Safety primarily into the conceptual phase of the aircraft interior design or to help with this intent in any project phase.

The three generic steps are proposed; step 1: Identification Phase => *Identification and parameterization of the component with requirement;* step 2: Translation Phase => *Safety threshold definition*; step 3: Evaluation and Implementation Phase => *Safety configuration definition* contributes with the designer or cabin safety specialist to split the project into components and perform analysis on each component. This analysis will bring a safety definition for each component and lastly to better identify which aspects will better contribute to the safety configuration definition. The Factors Influencing Behavioral Responses to Emergencies that ought to be considered in the step 3 goal was also introduced.

The use of this method drives the design team to discuss safety aspects of the interior component (e.g. a placard), monuments (e.g. stowage compartment for emergency equipment) and interior configuration (e.g. a new interior lay out), in a technical and methodological way instructing them to break down and analyze all the configuration components. In addition it will contribute to select an appropriate safety configuration to be designed and implemented. Ultimately, adding to cabin interior a value that can enhance the aircraft crashworthiness and passenger survivability.

The next chapter brings instances where this method could be used in real interior configuration development.

4 METHOD APPLICATION

To demonstrate the method application and its validation two approaches were used:
- Test Cases: a method was applied in two test cases in an actual project for aircraft interior configuration by the author;
- Application with different users: a method was applied in a design change case by two designers and one engineer also from the interior department.

The objective was to test the method in different users and collect different opinions about the method, to validate it and collect points to be refined or improved.

Each approach used different paths to collect the desired data. As mentioned above, the first one was a direct method application in problems faced in interior engineering and the second one was an exercise inside a classroom. The chapter 4.1 starts with two test cases in an actual project for an aircraft interior configuration and then in chapter 4.4 it is reported the exercise done by other users applying the method in a theoretical example.

4.1 CONTEXT DESCRIPTION

For a new aircraft model to receive its Type Certificate, attesting that model is airworthy, it is necessary to comply with all applicable airworthiness requirements.

As mentioned in Chapter 2 – table 2.2 there are several requirements related with cabin safety and interior structure. Requirements presented in this table were implemented based on research about aeronautical accidents which at the time of release were labeled crashworthiness requirements. To show compliance with these requirements, there are different means of compliance (MOC) accepted by regulatory authorities. It is possible to demonstrate the MOC via design review, report analysis, laboratory tests, aircraft tests etc. For cabin safety, in some cases, it is necessary to perform the tests using naïve volunteers (representing aircraft passengers).

Two of these tests have been selected to apply the DF_CS method and discuss the results yielded by them.

The tests selected are related to "Marking and Placards", which is a segment in cabin interior that frequently bring challenges and difficulties to the cabin project. The test outcome is either pass or fail depending upon the behavior of the volunteers during the test.

The steps described in Chapter 3 are strictly followed, as applicable to the proper content of the test case.

Procedure and Time Frame Method Application

As explained in Chapter 3, the Design for Cabin Safety Method aims to integrate the requirements of cabin safety into the conceptual phase of the aircraft interior design. Therefore, the method could be properly applied in any product development phase.

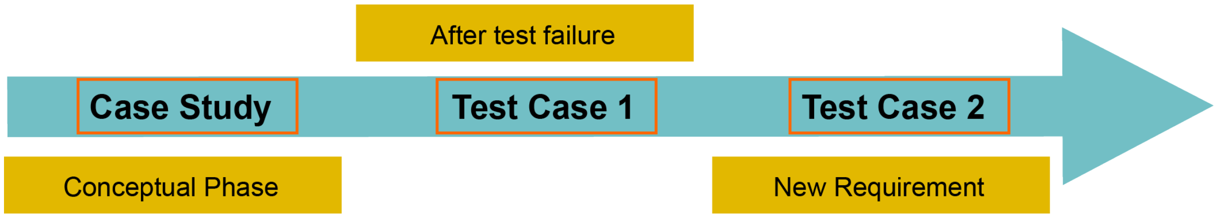
It is known that costs associated with changes in design conception are significant less than when the product is in production or in assembly phase. However, if during product evaluation it fails some compliance requirement, the DF_CS method could be applied to identify where it failed and contribute to better identify which are the possibilities to redesign the item with appropriate adherence to the specific requirement.

The cases adopted here to apply the method was selected among different cabin safety test and modification in different phases of the interior development (Figure 17) to demonstrate the relevance of the analysis involved in each method step and to allow this author to issue this dissertation according the company confidentiality regulations.

As detailed bellow, the method was applied in test case I after all the product development was done and after the product failed in a test to demonstrate compliance with its requirements. The difference here is applying a comparison of the conceptual phase of the product was that the user will have additional inputs collected from the test failure. Test case II has another scenario as the divan presented an occupancy limitation. The regulatory authority demanded a specific test with volunteers to demonstrate the efficacy of the solution adopted to address this limitation.

After method application in two test cases, an experiment is performed, calling participants to be trained in the method and apply it in the design conceptual phase for a new interior configuration. The objective was to collect data that could adjust the method for future use.

Figure 17 – Time Frame Method Application



Source: Author (2020).

4.2 DESIGN FOR CABIN SAFETY METHOD APPLICATION – TEST CASE I

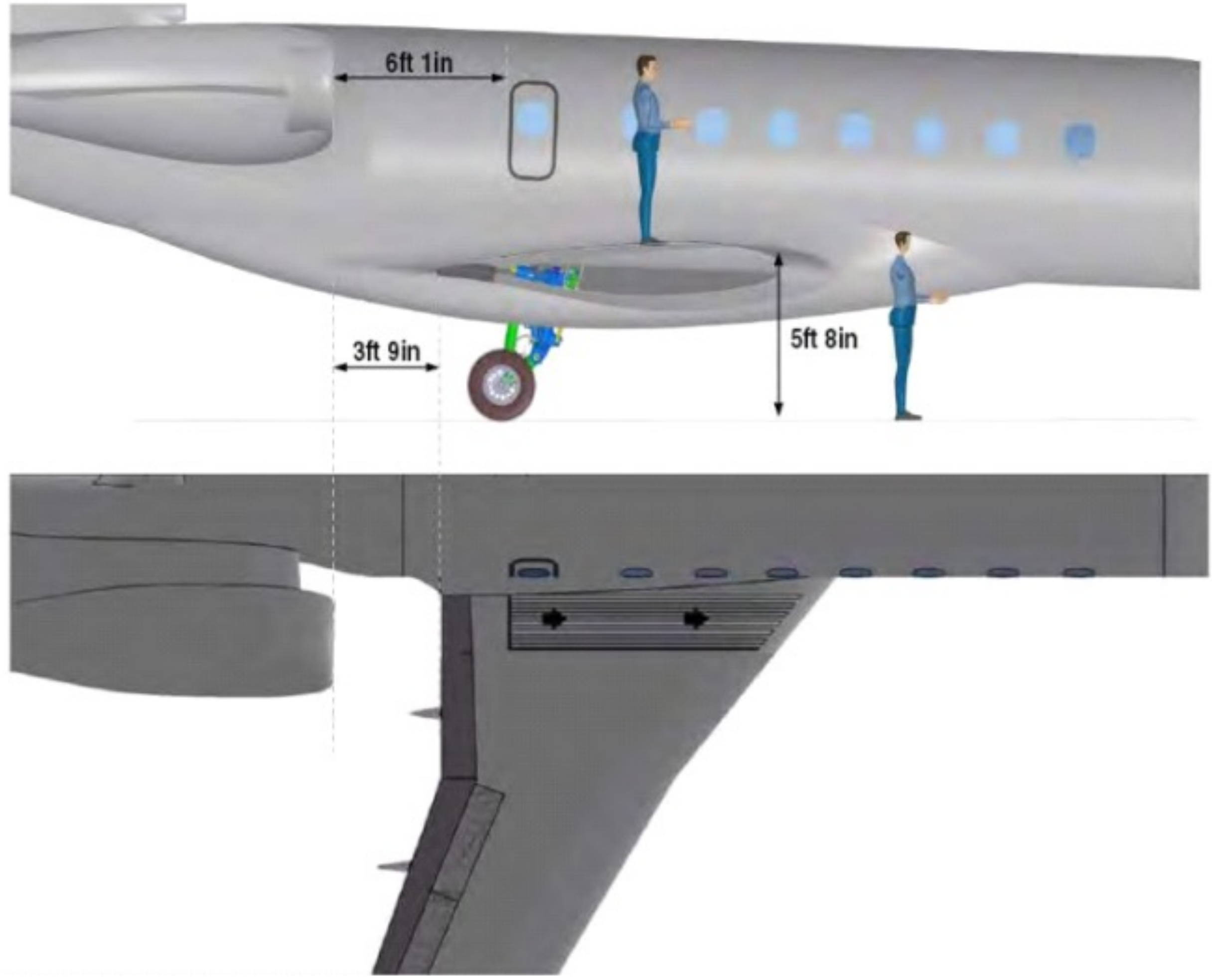
Test Case I : Overwing Exit Marking Effectiveness Test

The first case chosen to demonstrate the DF_CS method was based on a mid-size executive jet interior configuration, which is designed for a maximum of 12 passengers and has a main door for normal exit and an additional emergency exit labeled *Type III overwing exit*.

The Type III overwing exit is located on the right hand side of the fuselage close to the engine inlet and wing trailing edge. The 6ft 1in (1.8 m) distance to the engine inlet provides a reasonable escape area for identification of the escape route and proper evacuation. See Figure 18.

The evacuation route is indicated by markings on the wing with the help of outside emergency lights, the design intends to illuminate the path and provide guidance of the correct direction to escape. Evacuation forward is considered safer, however if the wing marking is not effective to lead the occupant toward the leading edge in the dark, the occupant may ignore the wing marking and decide to egress toward the trailing edge, which due the proximity to the airplane engine may be hazardous for the occupant.

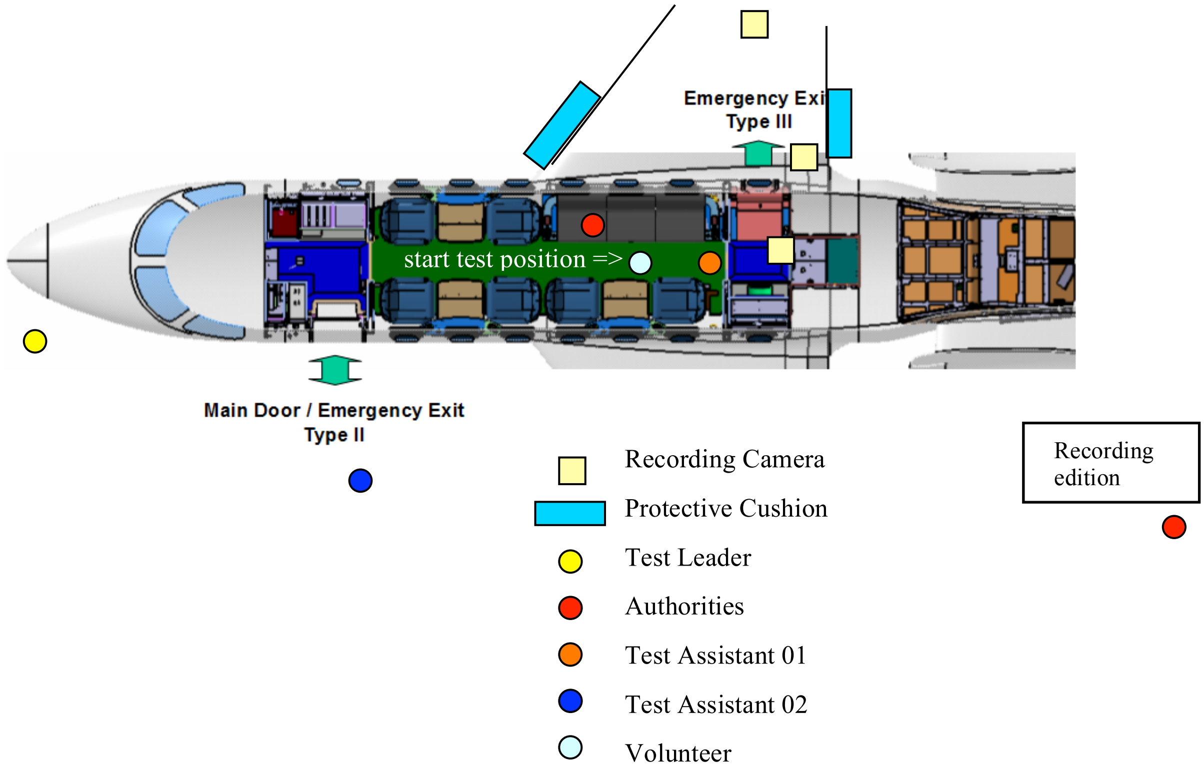
Figure 18 - Overwing exit - Dimensions



Source: Embraer EMB-550 (2014).

To demonstrate that the overwing marking and its illumination are effective to provide the proper orientation for the occupant (passenger and crew) to go towards forward direction, even in the dark condition, a test was agreed with regulatory authorities and registered in a test proposal with specific pass and fail criteria. The exit marking painted on the upper wing, close to the emergency exit, would show to be effective if at least 85% of the volunteers decided to move towards the wing's leading edge. For a group of 13 volunteers, no more than 2 failures would be acceptable.

Figure 19 - Overwing Exit Marking Effectiveness Test Setup Layout



Source: Embraer EMB-550 OWE marking effectiveness test proposal (2014).

As illustrated in Figure 19, this is the layout representing the scenario of the test as conducted. The test procedure consists of taking the volunteer inside cabin, to see the "start test position", then the test assistant 01 introduces the volunteer to the test procedure and provides the instructions that he or she shall follow the signals and markings to exit through the emergency door, passing over the wing to the ground.

According to the exit marking the volunteer will be considered a pass if he or she takes the left direction after exiting the airplane through the over wing exit, all other directions that the volunteer may take will be considered a fail.

In the first certification campaign, the solution developed for this OWE marking, the test failed. Some volunteers did not follow the exit marking properly, thus the design solution was not approved. In a situation like that the aircraft manufacturer shall redesign the solution indicating to regulatory authorities where the modification was introduced and repeat the test to be approved. It was in this scenario that the DF_CS method started to collaborate with the development team.

After a test failure, the failure analysis is not a simple, easy or obvious task to be performed. There are several variables that shall be studied in the test proposal. Considering the concept introduced in Chapter 3 about the different components of a system and the interactions between these components within the aviation domain, the factors influencing survival, were considered as:

- ✓ the configuration;
- ✓ the procedure;
- ✓ the environment;
- ✓ the behavior.

The content addressed by the DF_CS method is detailed as follows.

The DF_CS method receives as input a <standard configuration>, that in Test Case I was described above, and throughout the three steps of the method, it delivers the output <safety configuration> i.e., a configuration adherent to the safety requirements.

This section presents – step by step – the application of the DF_CS method for an Overwing Exit Marking Effectiveness test.

4.2.1 STEP 1: identification phase => identification and parameterization of the component with the requirement

DF_CS procedure begins with the identification of the components that are used through the method's execution. Thus, the input of the method first step is a standard configuration which contains information about what pieces compose the product and how we are interfacing with them.

The contribution of this first step is to guide the user to analyze and identify which are the primary factors that ought to be elected to be parameterized. As described in Chapter 3 – table 3.2, four significant groups of requirements were defined as a primary factor for the DF_CS method. Among these four groups there are several airworthiness requirements and also the Factors Influencing Survival that may have an influence on the project.

So, knowing configuration components, this phase aims to attribute parameters that can completely describe these parts. In addition, parameters that define how the configuration components interface will be clarified. As a result, parameterized components and parameterized integration interfaces are obtained.

Within the presented case of application, the identified components are: overwing exit marking and external illumination. The integration interface for these components are exit marking arrows, stripes as exit marking background, reflectance in the stripes, light intensity, number of spotlights and angle of illumination.

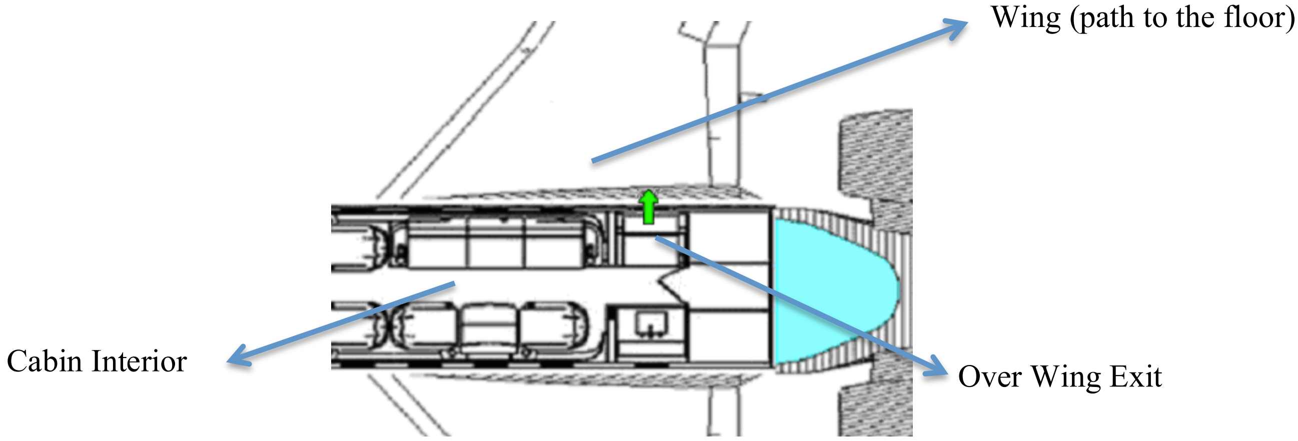
The procedure follows with the specification of parameters that describes each one of the components and integration interfaces.

Identify Requirements in the initial configuration

As described above, the standard configuration for this test case is composed of:
- an overwing exit marking (painted in the wing),
- the external illumination (that shall be on the over wing exit) and
- integration between the marking and the illumination

depicted in Figure 20.

Figure 20 - Standard Configuration



Source: Embraer EMB-550 (2014).

The development team shall evaluate how these components influence the passenger's behavior when they use the product and elect the ones that will be parameterized. As for this test case I, the method was applied after a test failure, in this case the user will also have inputs from the previous test results.

According to the DF_CS method described in Chapter 3, the user needs to deeply evaluate the standard configuration to identify the relevance of all the components considering which performance or dimensions that the item shall comply to the selected primary factors (cabin safety requirements). The development team evaluated the test failure data: films, pictures, volunteer questionnaires after the test, the cabin interior, the approach to the exit, the step up and down in the wing and the path towards the floor. In addition to the standard configuration components the factors related with (Table 3.3) were also evaluated:

- Human factor - behavior (volunteers – naive subjects): the man;
  - ✓ naïve volunteers behavior – prior and during the test
- Material factor – environment (marking design and illumination): the machine;
  - ✓ test set-up (aircraft configuration representing the scenario intended to test),
- Operational factor – procedure (test set-up, logistics and test execution): the environment.
  - ✓ logistics (aircraft, hangar, organization team, volunteers team, authorities etc.)
  - ✓ test execution (test itself).

These variables may or may not be considered as configuration components: the DF_CS user shall decide whether to introduce these variables or not in the case under analysis.

In this test case, these variables were very important in evaluating the failure root causes in the first test and very helpful in identifying the components that ought to be selected to be introduced in the DF_CS step 1.

According to the evaluation above, it was concluded that for this test case the standard configuration is:

- overwing exit marking;
- external illumination and
- exit marking and illumination interface.

Thus, it is necessary to show compliance with these 2 components (and its interface), considering that all other features that constitute this configuration are compliant with its specific requirements.

<u>Identify, besides the requirements what are other relevant items</u>

The parameterization of the component with its requirement is carried out as follows:

Component α: overwing exit marking

Requirement:

All aircraft that have an over wing emergency exit shall comply with the following requirement:

- 14 CFR FAR §25.810 (c)(1) - *Emergency egress assist means and escape routes*

(c) An escape route must be established from each overwing emergency exit, and (except for flap surfaces suitable as slides) covered with a slip resistant surface. Except where a means for channeling the flow of evacuees is provided—

(1) The escape route from each Type A or Type B passenger emergency exit, or any common escape route from two Type III passenger emergency exits, must be at least 42 inches wide; that from any other passenger emergency exit must be at least 24 inches wide.

(2) The escape route surface must have a reflectance of at least 80 percent, and must be defined by markings with a surface-to-marking contrast ratio of at least 5:1.

Component **β**: external illumination

Requirement:

- 14 CFR FAR §25.812(g)(1) – *Exterior emergency lighting*

(g) Exterior emergency lighting must be provided as follows:

(1) At each overwing emergency exit the illumination must be—

(i) Not less than 0.03 foot-candle (measured normal to the direction of the incident light) on a 2-square-foot area where an evacuee is likely to make his first step outside the cabin;

(ii) Not less than 0.05 foot-candle (measured normal to the direction of the incident light) for a minimum width of 42 inches for a Type A overwing emergency exit and two feet for all other overwing emergency exits along the 30 percent of the slip-resistant portion of the escape route required in §25.810(c) that is farthest from the exit; and

(iii) Not less than 0.03 foot-candle on the ground surface with the landing gear extended (measured normal to the direction of the incident light) where an evacuee using the established escape route would normally make first contact with the ground.

Interface: exit marking and illumination interface

Requirement:

- the requirement for this interface does not come from the 14 CFR FAR, it comes from the lessons learned in previous configurations and in this case came from the first certification campaign; the illumination shall not illuminate another area then first step outside the OWE, escape route and first ground contact (any focus of light out this 3 spot may contribute to passenger misleading)

<u>Evaluate requirements and other items</u>

The parameterized components and integration is summarized in the table 4.1.

Table 4.1 – Components / Parameters / Integration

	COMPONENTS	**PARAMETERS**
COMPONENTS & PARAMETERS	OVERWING EXIT MARKING	must be at least 42 inches wide; that from any other passenger emergency exit must be at least 24 inches wide
		must have a reflectance of at least 80 percent, and must be defined by markings with a surface-to-marking contrast ratio of at least 5:1
	EMERGENCY WING LIGHTS SYSTEM	(i) Not less than 0.03 foot-candle (measured normal to the direction of the incident light) on a 2-square-foot area where an evacuee is likely to make his first step outside the cabin;
		(ii) Not less than 0.05 foot-candle (measured normal to the direction of the incident light) for a minimum width of 42 inches for a Type A overwing emergency exit and two feet for all other overwing emergency exits along the 30 percent of the slip-resistant portion of the escape route required in §25.810(c) that is farthest from the exit; and
		(iii) Not less than 0.03 foot-candle on the ground surface with the landing gear extended (measured normal to the direction of the incident light) where an evacuee using the established escape route would normally make first contact with the ground.
COMPONENTS & INTEGRATION	EXIT MARKING & ILLUMINATION	The interface among the parameters is straightforward: the illumination must be proper positioned all over the exit marking and in the ground (considering the first step outside the cabin and ground)

Source: Author (2018).

4.2.2 STEP 2: translation phase => safety thresholds definition

After the identification and parameterization, the DF_CS method proceeds with the Safety D definition for each of the identified parameters. In addition to this step, the Semantic Translator – Crashworthiness to design requirements guidelines – is applied: it translates the crashworthiness requirements into design requirements, considering the main purpose of the rulemaking for the requirements.

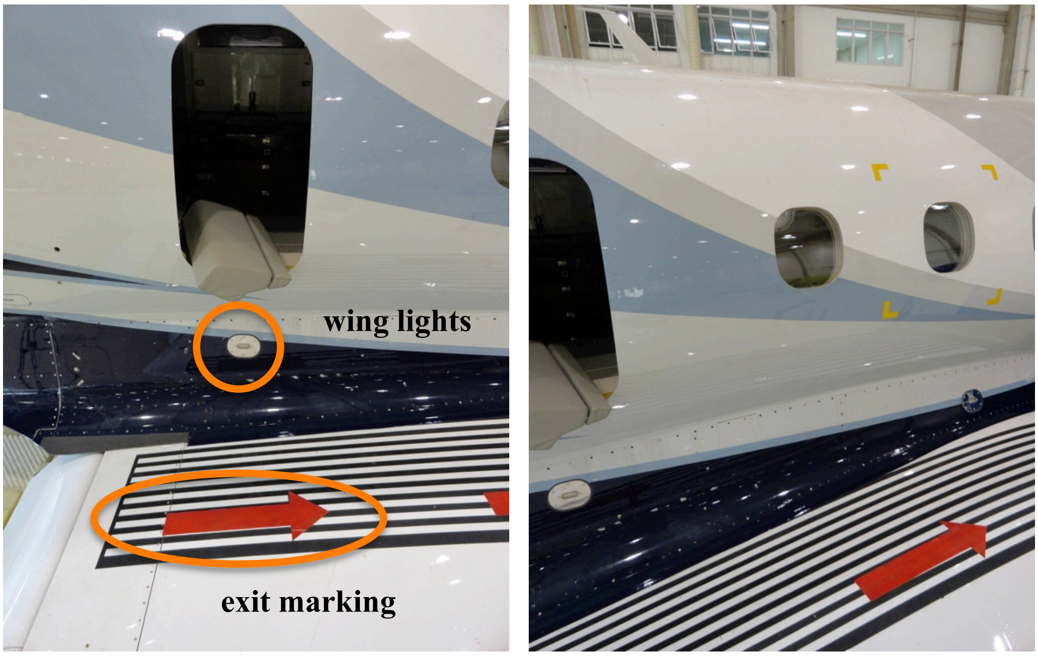
Safety D - Semantic Translator – Crashworthiness to design requirements

Step 1 has identified and parameterized two components and their interface:,

- ✓ the overwing exit marking
- ✓ the emergency wing lights system
- ✓ exit marking and illumination interface

as depicted in Figure 21 (this was the original concept prior to applying the DF_CS method – labeled herein as original design).

Figure 21 - Overwing Exit Marking and Wing Lights – Original Design (prior to use the DF_CS)



Source: Embraer EMB-550 (2014).

As described in Chapter 3, in step 2 the task is to input in the semantic translator engine the parameters for the two components identified in the Step 1 and collect as output the safety aspects that shall be present in the components design. This process was documented in Table 4.2.

Thus, according to the four questions introduced in Chapter 3.2.2 it was possible to elaborate two safety aspects for the overwing exit marking and also two safety aspects for the emergency wing lights.

Table 4.2 – Components and Parameters with Safety Aspects

	COMPONENT	**PARAMETERS (input)**	**SAFETY ASPECTS (output)**
COMPONENTS & PARAMETERS	OVERWING EXIT MARKING	(i) must be at least 42 inches wide; that from any other passenger emergency exit must be at least 24 inches wide; (ii) must have a reflectance of at least 80 percent, and must be defined by markings with a surface-to-marking contrast ratio of at least 5:1	The exit marking shall “tell" the user what to do just by looking.
			The exit marking painted on the upper wing, close to the emergency exit, shall be effective to let passengers to decide to move towards the wing leading edge, i.e. take left after “escape” from the overwing exit.
	EMERGENCY WING LIGHTS SYSTEM	(i)Not less than 0.03 foot-candle (measured normal to the direction of the incident light) on a 2-square-foot area where an evacuee is likely to make his first step outside the cabin; (ii) Not less than 0.05 foot-candle (measured normal to the direction of the incident light) for a minimum width of 42 inches for a Type A overwing emergency exit and two feet for all other overwing emergency exits along the 30 percent of the slip-resistant portion of the escape route required in §25.810(c) that is farthest from the exit; and (iii) Not less than 0.03 foot-candle on the ground surface with the landing gear extended (measured normal to the direction of the incident light) where an evacuee using the established escape route would normally make first contact with the ground.	Light shall illuminate passenger first step outside the cabin, the passenger route in the wing and passenger first ground contact.
			Light focus shall not illuminate other areas that may contribute to the passenger misinterpreting the exit marking and let he or she take inappropriate direction to descend from the wing.

Source: Author (2018).

The safety aspects highlighted in the Table 4.2 are the guidelines for interior designers to achieve (translate) what the parameters or requirements are stating.

It is worth mentioning that the quantity of safety aspects listed in Table 4.2 varies according to the quantity of components and as happened in this test case, each component has more than one safety aspect.

Specifically, for this test case, the safety aspects were generated after a test failure. Even though the overwing marking originally proposed and shown in Figure 21 may seem obvious for some naive volunteers, i.e. indicating that the evacuee should leave the airplane and move towards the wing leading edge, or go left after "escape" from the overwing exit; some naive volunteers did not performed as expected.

After the test failure, the three factors identified in the Step 1, namely, human factor, material factor and operational factor, were also assessed and with the DF_CS method application all these factors were modified, changing the result of the test.

The overwing exit marking and exit light were redesigned as depicted in Figure 22, 23, and 24 and has shown to be effective once, in a new test, all the required volunteers correctly followed the indicated direction, towards the wing leading edge, and also stated in the post test questionnaire the observation and understanding of the markings. The first eleven volunteers left the aircraft through the opened Type III emergency exit, over the wing, towards the wing leading edge and jumped to the protection foam on the ground. After this, in agreement with Authorities, the test was finished and the last two volunteers were not asked to perform the test.

Regarding the primary factors here considered:

- the emergency light "cone focus" was adjusted
- the overwing exit marking was redesigned (important detail to highlight was the introduction of a man running pictorial)

both complied with the safety aspects mentioned in Table 4.2 and approved in the development tests and later in certification test.

Also, with the analysis carried out in the DF_CS step 1 the method contribute for the identification of the factors influencing the test results guiding the team to do the following adjustments in the test and its configuration:

- ✓ the configuration to which the component will be inserted for use by the passenger - mentioned above regarding cone focus and exit marking redesign;
- ✓ the environment / situation where the component will be used such as normal situation, emergency situation, with / without smoke in normal or emergency lighting -

adjusting the hangar to be completely dark without any distracting light that could drive the volunteer to a different direction

✓ human behavior that considers biological, psychological and cultural attributes of the individual as a passenger - controlling the logistics of the test that do not introduce any additional anxiety, panic or burden to the volunteer to perform the test

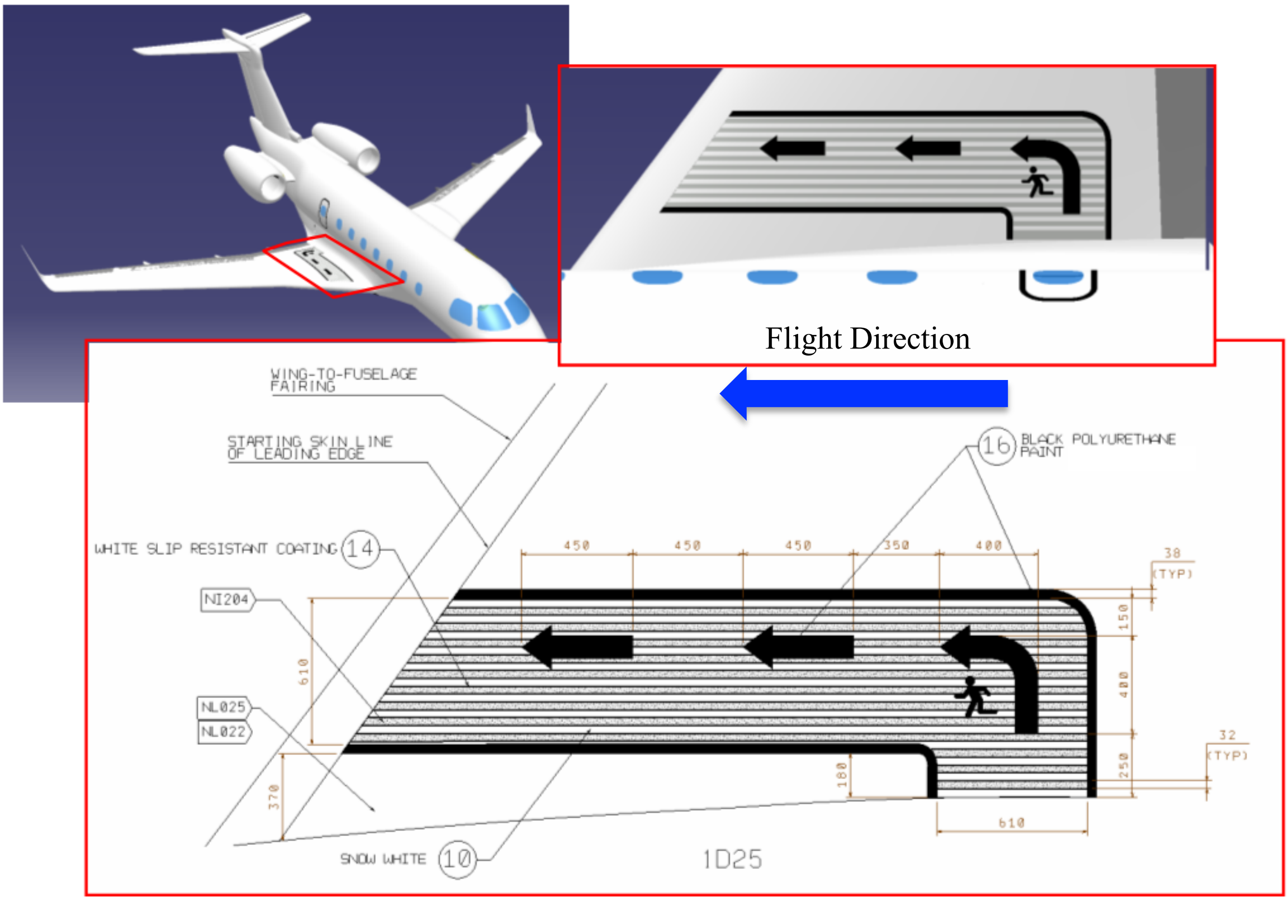
✓ the usability (affordance) of the equipment - introducing the pictorial of the man running into the exit marking.

Without the DF_CS method, the analysis of the failed configuration could involve several irrelevant variables leading to a redesign that would not result in a relevant difference. Here it is possible to observe the gap that existed without a proper method to evaluate a new configuration. The DF_CS conducted the user to evaluate each configuration component according to the primary factors. Moreover, after all configuration components were identified in this step 2, the specific safety aspects for each component was extracted from the requirements and through the semantic translator to reach a design requirement that could better address the airworthiness requirement.

Figure 22 - Overwing Exit Marking

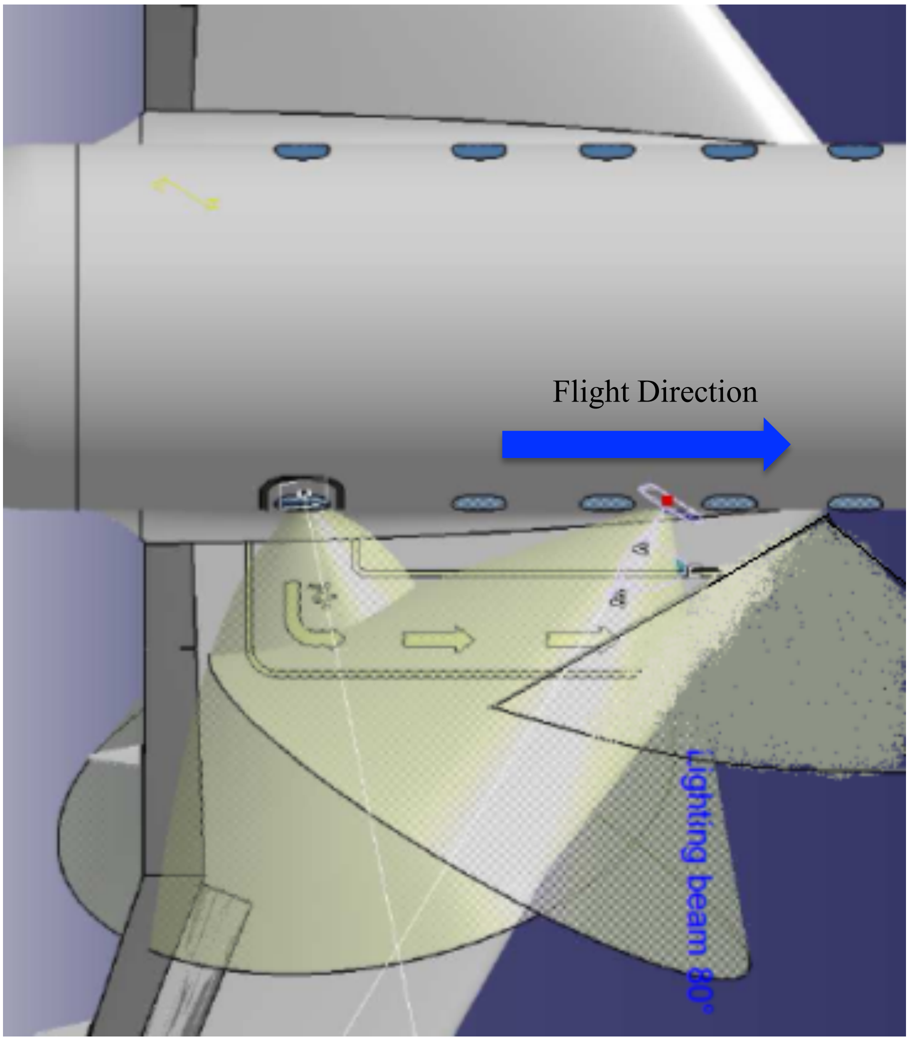
Source: Embraer EMB-550 (2014).

Figure 23 - Overwing Exit Marking Design Details



Source: Embraer EMB-550 (2014).

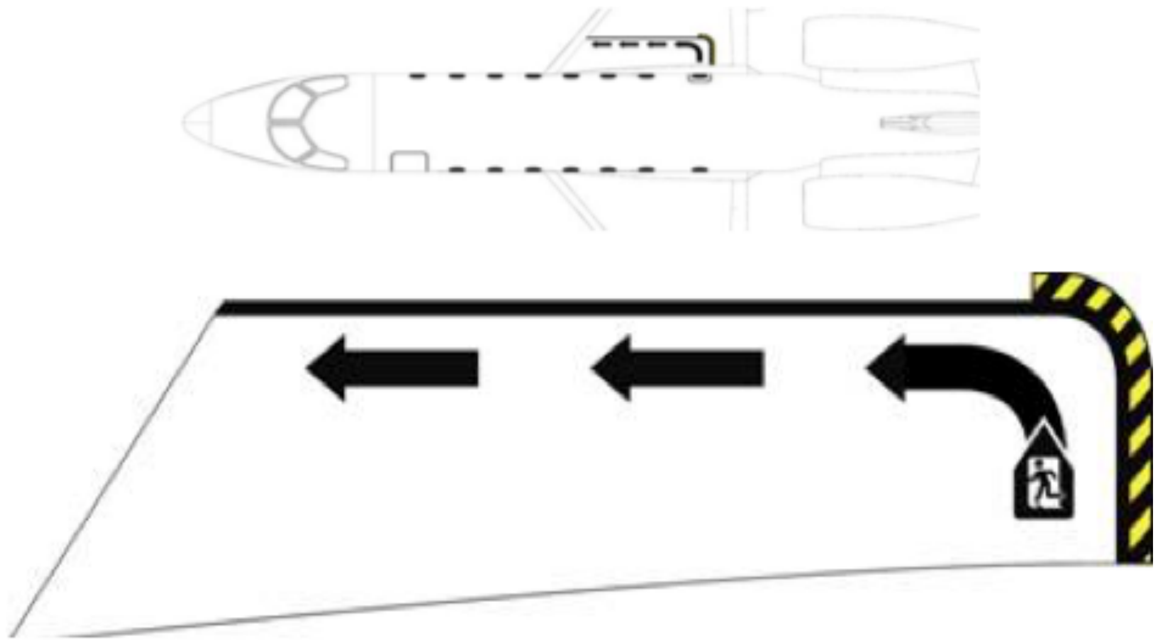
Figure 24 - Overwing Exit Lighting Beam



Source: Embraer EMB-550 (2014).

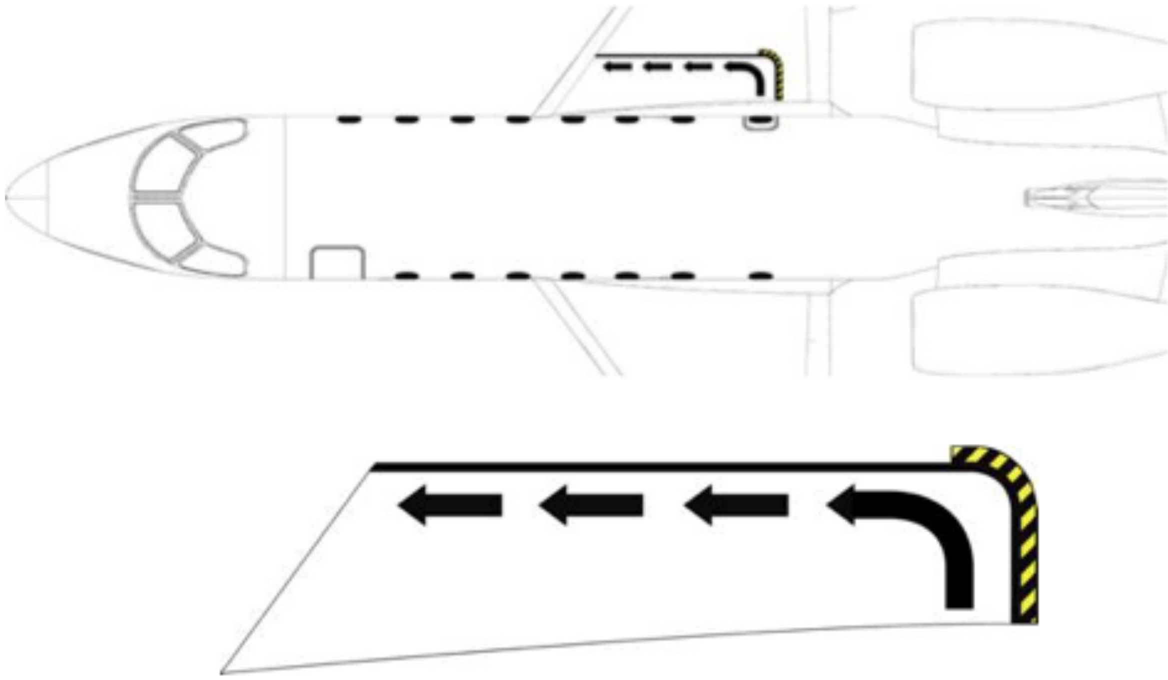
Figures 25 and Figure 26 illustrate the overwing exit marking that did not comply with the safety aspects defined herein, because in the development tests, it did not lead passengers to decide to move towards the wing leading edge.

Figure 25 - Overwing Exit Marking - Redesign Proposal I



Source: Adapted from the Embraer design proposal placards (2014).

Figure 26 - Overwing Exit Marking - Redesign Proposal II



Source: Adapted from the Embraer design proposal placards (2014).

4.2.3 STEP 3: evaluation and prioritization phase => *safety configuration definition*

The third step of the method aims to evaluate and prioritize the items that will compose the safety configuration, which can cover, as much as possible, the defined Safety D.

Depending on the numbers of the Safety D generated in step 2, step 3 may be a step to take with or without evaluation and prioritization. If the case generates few, not complex or expensive Safety D, the best is to adopt all. However, if step 2 generates several Safety D, the IPD shall evaluate which ones will bring more safety for the configuration and prioritize its implementation. In this test case, it was not necessary to evaluate which safety aspects should be prioritized in comparison with others; besides, a Safe Configuration was adopted considering all the aspects found in step 2. Thus, as shown in Table 4.3 all of Safety D was adopted in the Safety Configuration.

Table 4.3 – Safety Configuration Definition

	COMPONENTS	**PARAME-TERS**	**SAFETY ASPECTS (Safety D)**	**SAFETY CONFIGURA-TION DEFINITION**
COMPONE-NTS & PARAME-TERS	OVERWING EXIT MARKING	(i) and (ii)	The exit marking shall “tell" user what to do just by looking.	Safety D adopted.
			The exit marking painted on the upper wing, close to the emergency exit, shall be effective to let passengers to decided to move towards the wing leading edge, i.e. take left after “escape” from the overwing exit.	Safety D adopted.
	EMERGENCY WING LIGHTS SYSTEM	(i), (ii) and (iii)	Light shall illuminate passenger first step outside the cabin, the passenger route in the wing and passenger first ground contact.	Safety D adopted.
			Light focus shall not illuminate other areas that may contribute to the passenger misinterpreted the exit marking and let he/she to take inappropriate direction to get the group.	Safety D adopted.

Source: Author (2018).

4.3 TEST CASE II - OCCUPANCY PLACARD EFFECTIVENESS

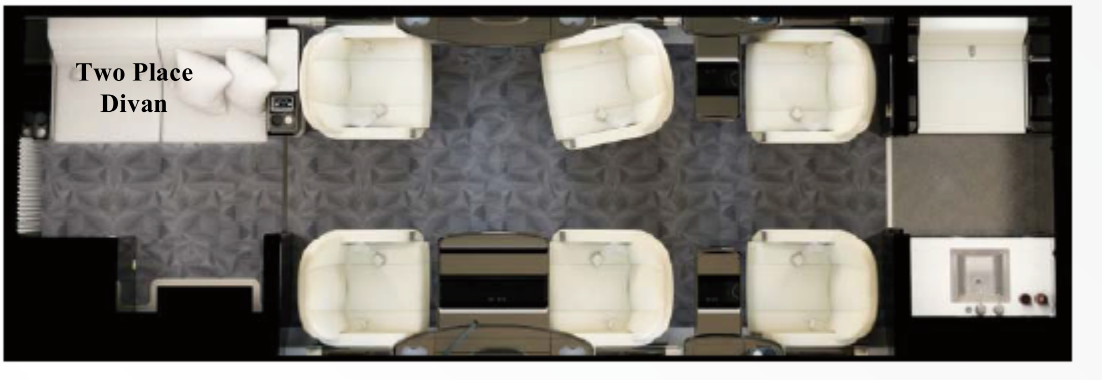
All the definitions and arguments presented in Test Case I remain valid for test case II and is treated with the same perspective.

Test Case II : Occupancy Placard Effectiveness

Six seats compose the aircraft configuration shown in Figure 27 plus a two-place divan (i.e. sofa) also labeled side-facing seat. For a side-facing seat like this divan, there are specific dynamic airworthiness requirements that must be complied. As the dynamic certification campaign was not over and the aircraft operation was about to begin, the adopted solution was to have an occupancy limitation during the phases of taxi, takeoff and landing. The limitation was only in the most aft position of the divan (highlighted in yellow in Figure 28). The limitation is only applicable when a passenger is seated alone in the divan. That is, there is nobody seated in the same divan at the same time.

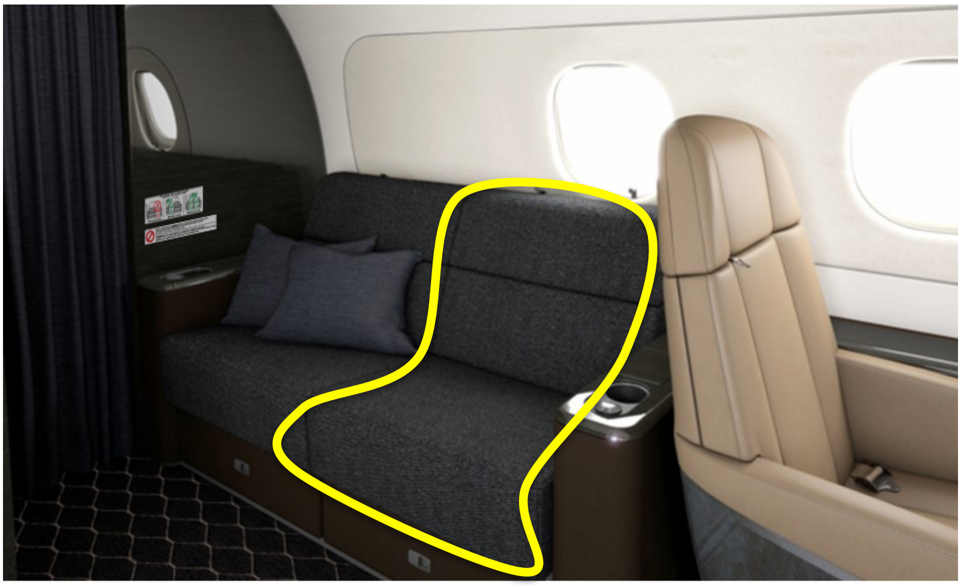
It was decided to use a placard to indicate to passengers that limitation. Thus, as the case is regarding a seat occupancy limitation the regulatory authority demands a test with volunteers to demonstrate the placard effectiveness. Considering the time frame where the method was applied, the test case method was applied after the interior was installed and a new requirement was introduced for this configuration.

Figure 27 – Interior Configuration with Seats and Divan



Source: Adapted from the Embraer EMB-545 Cabin Interior for marketing (2016).

Figure 28 - Divan Limitation Position



Source: Adapted from the Embraer EMB-545 Occupancy Placard Effectiveness Test Proposal (2016).

As mentioned, the seat occupancy limitation was only for the flight phases: taxi, takeoff and landing (TTL). According to the context of this configuration, a placard is an appropriate acceptable solution to show compliance with the limitation requirement. If the limitation was for all flight phases a different solution should be adopted in order to block the seat use. Considering the typical certification plan for the installation of a placard, the means of compliance adopted and accepted by the regulatory authorities, is a cabin inspection. As this placard refers to an occupancy limitation, the regulatory authority understood that the verification of the placard effectiveness should be via certification test using naïve volunteers. In Chapter 3.2.1, it is mentioned that DF_CS started identifying the interior component that is being planned to be installed or designed for a new configuration. This test case II refers to a new placard with the peculiarity that ought to be design and installed and its effectiveness must be demonstrated through a test with naïve volunteers.

4.3.1 STEP 1: identification phase => identification and parameterization of the component with requirement

Standard Configuration

In this step, the standard configuration is the input that the DF_CS method receives from the product according to the configuration conditions for the case.
As an additional event to test the naïve volunteer, after seated in the proper position, shall fasten the seat belt (for this divan it is a three point seat belt).

Identification Requirements in the standard configuration

The standard configuration (Figure 29) for this case is:

- a placard design indicating the occupancy limitation for TTL and indicating that the passenger shall fasten the seat belt;
- the position where the placard should be installed;
- a two place divan with an occupancy limitation;
- the test to be performed with naïve volunteers to demonstrate the placard effectiveness;
- an executive cabin interior.

Figure 29 - Standard Configuration

Source: Adapted from the Embraer EMB-545 Occupancy Placard Effectiveness Test Proposal (2016).

<u>Identify, besides the requirements, what are the other relevant items</u>

Among the 5 items identified in the standard configuration as relevant for the method, the one that has a regulated airworthiness requirement to comply with is the placard:

Component **α**: placard

Requirement: Marking and Placards

§25.1541 General.

(a) The airplane must contain—

(1) The specified markings and placards; and

(2) Any additional information, instrument markings, and placards required for the safe operation if there are unusual design, operating, or handling characteristics.

(b) Each marking and placard prescribed in paragraph (a) of this section—

(1) Must be displayed in a conspicuous place; and

(2) May not be easily erased, disfigured, or obscured.

The requirement §25.1541 already addresses three items that compose the standard configuration: the placard as an item, the information that the placard ought have and the appropriate position to be installed ("must be conspicuously placed").

The two other standard configuration items the test procedure and the executive cabin interior (i.e. the environment where the placard shall be installed and tested), ought to be evaluated to verify which parameterization they need to receive. Based on our experience in the application of the DF_CS method, it was identified that the "physical components" like interior monuments, seat, placards etc. are not the only components that deserve attention in the identification and parameterization phase. The non-tangible items like the test procedure and the environment where the item will be installed and used shall also be evaluated to receive the appropriated parameterization.

The layout scenario on which the test was conducted is illustrated in Figure 30.

The test procedure in summary consists to take the volunteer inside the cabin, at a spot "start test position" (in Figure 30 represented by the blue circle), the test leader will ask the test subject to stand in front of the divan at the position shown and will provide a briefing mentioning that s/he is the only passenger on today's flight with the divan seating and ask the volunteer to locate and understand the instruction on the placards, and then be seated for takeoff. Besides other specific features found in executive interiors the seat belt for this configuration was a three point seat belt, different from the standard two-point seat belt adopted in commercial airplanes

For each volunteer, the test will be considered a pass if s/he sits in the permitted position and fastens the seat belt, all other positions that the volunteer sits will be considered a failure.

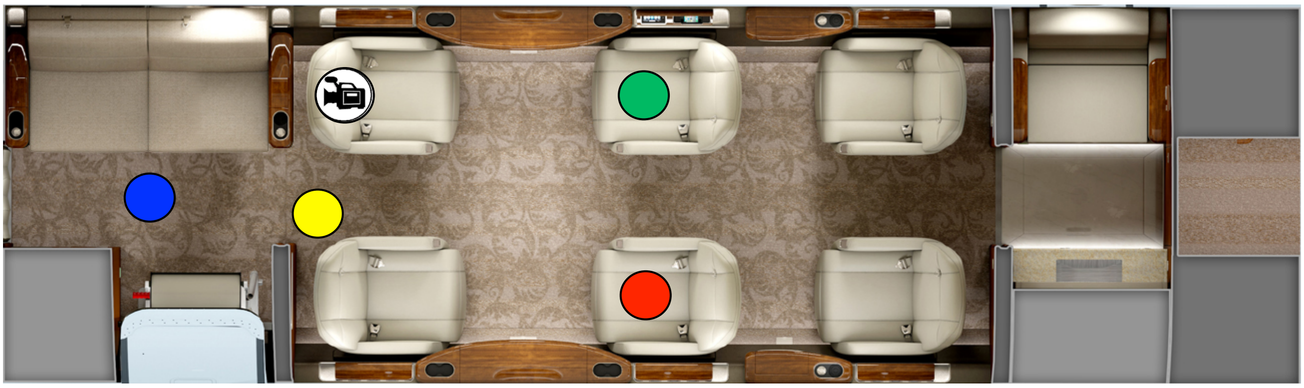
In the development test, it was used a different placard design, different placard position and ran the test without introducing the volunteer to the aircraft configuration. According to the pass/fail criteria it was observed more failures then pass results. That was where the DF_CS started to help the development team.

Development test confirmed what DF_CS in Chapter 3 introduced about the different components of a system and the interactions between these components:

- ✓ the configuration;
- ✓ the procedure;
- ✓ the environment;
- ✓ human behavior;
- ✓ the usability (affordance) of the equipment.

The configuration and the environment here is an executive jet interior. Which is not the common cabin interior (commercial aircraft) that the majority of passengers (or naïve volunteers) are used to travelling with. Different from test case I the naïve volunteer is not testing a feature or procedure in emergency condition. The situation is in normal condition, so the human behavior is not affected by nervousness, anxiety, panic etc. However, attention is required to identify and understand the placard in order to sit in the allowed position. The affordance here shall count with the designer talent to transmit the information (where it is allowed or not to be seated) through the placard.

Figure 30 - Occupancy Placard Effectiveness Test Setup Layout



	Test Leader
	Authorities representative
	Test Assistant
	Naïve Volunteer
	Video Camera

Source: Adapted from the Embraer EMB-545 Occupancy Placard Effectiveness Test Proposal (2016).

Evaluate requirements and other items

As mentioned in Chapter 3 the Parameterized Components and Integration output of this phase is a clear definition regarding each component and respective requirement/characteristics each of them shall comply. Thus the placard, its design and its location shall comply with requirement §25.1541 and the test and the environment shall provide contribute with the intent of the installation of the placard.

4.3.2 STEP 2: translation phase => safety thresholds definition

After the identification and parameterization, the DF_CS method proceeds with the Safety D definition for each of the identified parameters. In addition to this step, the Semantic Translator – Crashworthiness to design requirements guidelines – is applied. It translates the crashworthiness requirements into design requirements, considering the main purpose of the rulemaking for the requirements.

Safety D - Semantic Translator – Crashworthiness to design requirements

Among the standard configuration identified in the step 1 it were selected to have safety definition with three components:

- ✓ a placard design with occupancy for TTL;
- ✓ the position where the placard should be installed;
- ✓ the test procedure to be performed in the executive cabin interior (test environment) to demonstrate the placard effectiveness.

As mentioned in the Step 1, the only component in this case that has defined airworthiness requirements is the placard. Thus the parameters for this component were dictated by the requirement text. Parameters for the test procedure and test environment were generated based on experience and were performed in a cabin safety test with naïve volunteers for executive aircraft and evaluated the specific details about the configuration, related with the test procedure and with the environment where the test took place.
Table 4.4 presents the sematic translation for each component/parameter.

Table 4.4 – Components and Parameters with Safety Aspects

	Components	Parameters (input)	Safety Aspects (output)
Components & Parameters	SEAT OCCUPANCY PLACARD	The airplane must contain: (1) The specified markings and placards; and (2) Any additional information, instrument markings, and placards required for the safe operation if there are unusual design, operating, or handling characteristics.	As the requirement dictate and the condition presents the placard shall contain the information for safe operation according the unusual design of the seat. Thus the placard shall properly indicated the position in the two place divan where is allowed or not to be seated for TTL. In addition the placard shall to indicate that when seated the passenger shall fasten the seat belt.
	INSTALLATION PLACARD POSITION	Must be displayed in a conspicuous place	The installation position ought be a place that “facilitates" the passenger awareness concerning the placard position and it’s reading. The affordance here is conspicuousness that may be interpreted as: easily seen or noticed / readily visible or observable.
	TEST PROCEDURE AND TEST ENVIRONMENT	Test procedure and the test environment shall contribute with the intent of the installation of the placard	Test procedure shall adopt procedural factors: - that provides naive volunteer familiarization with the test environment, - that positioned the volunteer in the appropriated position to perform the test and - that provide brief guidance to put the volunteer in an awareness condition to properly act according the test procedure.

Source: Author (2018).

Safety aspects presented in Table 4.4 for the components: <Test Procedure and Test Environment> does not have parameters that come from the FAR requirements. It comes from dedicated analyses and translation that is performed in step 2 of the DF_CS method. When evaluating the test procedure, it was detected that a familiarization for the volunteers was required because the test took place inside an executive interior with specific features for this aviation. In addition, the position where the volunteer shall be positioned to receive the test instructions were identified in this phase that is relevant for better understanding and comprehension of the test procedure.

4.3.3 STEP 3: evaluation and prioritization phase => *safety configuration definition*

The third step of the method aims to define a safety configuration, which can cover, as much as possible, the defined Safety D.

As mentioned in Step 1, to better understand the whole test for this configuration with the new requirement about the divan limitation, development tests were performed prior to using the DF_CS method. Test results were assessed and based on this assessment the conclusion was that attention should be dedicated at: i) placard installation position; ii) the briefing that was addressed to the naïve volunteer and iii) the placard quality design.

Regarding the position to install the placard, it was not an easy decision. The tendency was as illustrated in Figure 31, to install above the window right near the seat position where it was not allowed to sit. The placard could be noticeable prior to the passenger sitting. However, after being seated, how s/he would they read the placard to evaluate the proper position? The nearest spot was the seat back near the divan (Figure 30 – where camera was installed). However, if the seat was out of the position the passenger will not see the placard. Thus, it was decided to install the placard in the divider near the most forward position of the divan. The disadvantage was the distance that this region was from the most aft divan seat position. The test attested that final position was appropriated.

Figure 31 - Seat Occupancy Placard Installation Position

Source: Adapted from the Embraer EMB-545 Occupancy Placard Effectiveness Test Proposal (2016).

Figures 32 illustrates the initial proposal and Figure 33 the final proposal and the one that was tested and approved. There are few details that were changed from proposal 1 and the final proposal:

i) removed the check mark (in green) from the chest of the representative passenger, the motivation was to highlighted the position not the passenger;

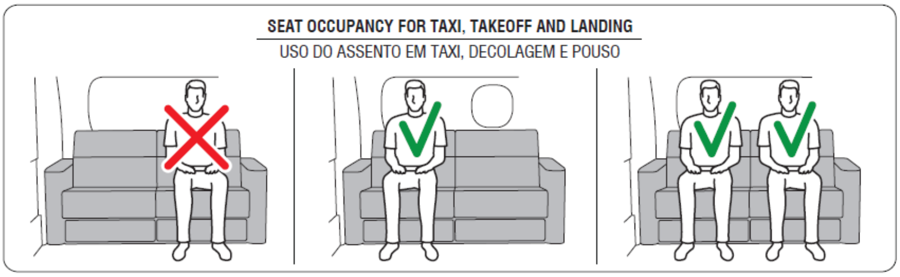
ii) changed the way to identify the prohibited position from the red cross to red circle (⊘), among the designers and some interview performed it was identified that this red mark circle is more interpreted as prohibited condition;

iii) included in the passenger representation the seat belt buckled, this was a imposition from the regulatory authority that the act to buckle the seat belt must be considered part of the test pass;

iv) it was highlighted in gray the forward divider to contribute with the volunteer to localize s/he position inside the airplane;

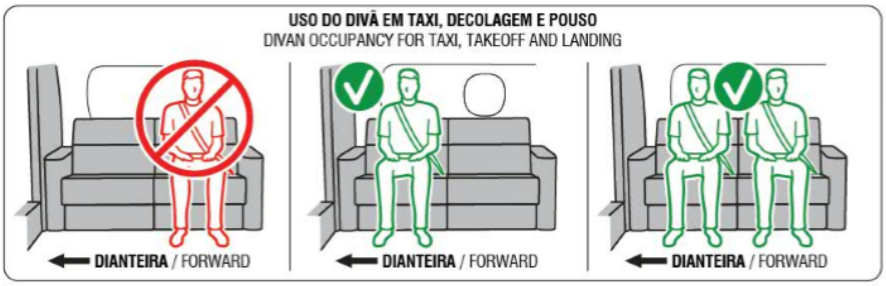
v) it was included the words identifying the airplane fly direction (Dianteira / Forward) also to contribute with the volunteer to localize s/he position inside the airplane.

Figure 32 - Seat Occupancy Placard (initial design)



Source: Adapted from the Embraer EMB-545 proposals for placard design (2016).

Figure 33 - Seat Occupancy Placard (final design)



Source: Adapted from the Embraer EMB-545 proposals for placard design (2016).

Moreover, the last component that was changed according to the DF_CS method was the test brief. Usually the regulatory authorities allow the industry to have a test brief to all volunteers to provide basic instructions regarding the test procedure and regarding what is expected from the volunteer. In particular for this test, each volunteer had a previous familiarization inside the airplane (Figure 30). The test was performed on an executive jet with seats, three point safety belt, interior monuments different from the ones that the majority of the passengers usually see and used in commercial flights, the authorities allow the test owner to do this familiarization.

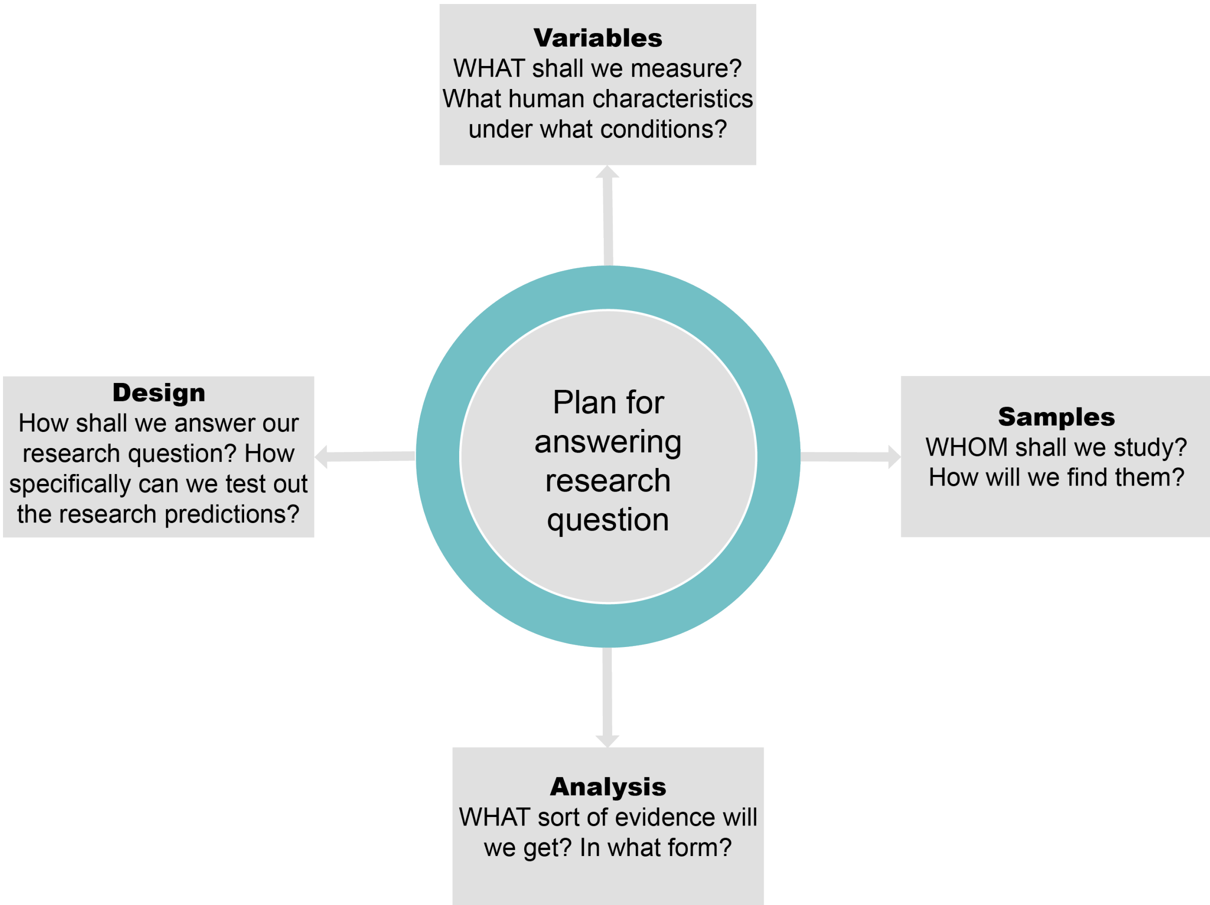
4.4 METHOD APLICATION BY USERS

4.4.1 Context description

After the method application in a real test case by this author, the method was introduced and applied for different users without previous experience. The goal was to observe the application results along with opportunities for improvement. The case study was a design change for a new interior configuration for commercial jets.

According to Coolican the key decision areas in a case study or research project is illustrated in the Figure 34 (Coolican, 2014).

Figure 34 – Key Decision areas in a Research Project



Source: Hugh Coolican (2014)

Analysis: What sort of evidence will we get? In what form?

The evidences that we are looking for in this case study are:
- evaluate the method learnability;
- investigate if the method application for different users results in a convergence of data results and
- assess the time used by participants to follow the method and reach the results.

The evidences will be shown in form of report at the end of the study.

Variables: What shall we measure? What human characteristics under what conditions?

It will be measured the method learnability and the time to reach results.

Samples: Whom shall we study? How will we find them

We will study designers and engineers that work with interior design and certification. We find them inside the aircraft manufacturing industry.

Design: How shall we answer our research question? How specifically can we test out the research predictions? (The design here is the overall structure and strategy of the research study)
The case study structure was divided in two sections: training the participants with the method and through a design change for a new interior configuration to collect data to do the analyses considering the three points of the analysis (above mentioned).

4.4.2 Design for cabin safety method application <experiment done by other users applying the method in a theoretical example>

The procedure to follow to do an interior design change or new configuration at interior engineering depends on each interior design or engineering.

As “creativeness” and technical sources, there are lessons learned data banks, a manual with best practices for interior design, all the airworthiness requirements with specific guidance as advisory circulars, previous Issue Papers and Special Conditions from regulatory authorities, all to be evaluated to verify what is applicable or not for that specific change.

Defining the Participants Profile

The selection of the participants was oriented by interior designers and engineers with at least a minimum of 10 years of experience in interior engineering. These professionals were selected with experience in the diverse types of interior modification with the goal to do the analyses mentioned above, with the possibility to do an association between the perceptions about the cabin safety importance in the interior design. As mentioned, they are also employees of the aircraft manufacturer, two of them are interior designers and one an interior engineer. As a cabin safety specialist, this author had the opportunity in different projects to deal with these volunteers for a specific project or to solve a specific problem.

Table 4.5 – Characterization of the Specialists Who Participated in the Study

Specialist	Professional Experience (years)	Graduation and Qualification
Designer	15	Industrial Designer. Specialized in graphic arts associated with the product and advertising (such as iconography, technical illustration and image processing) and product development (with a focus on conceptualization and modeling). Provides support to interior engineering teams in interior configuration scope definitions and product development. He has already worked in advertising agencies and in design of fairs and events.
Ergonomist	18	Bachelor in Advertising. Experience of projects in Catia and ergonomic evaluations of the product. Worked in interior design in the evaluation of ergonomics in aircraft of the commercial, executive, defense and agricultural categories.
Engineer	15	Interior Engineer with more than 15 years at Embraer. Working in interior engineering for commercial and executive jets. Experience with design, engineering and certification for different scope of work related with interior engineering.

Source: Participants Resume (2019).

Elaboration of the script for the analysis

The script adopted to collect the data for the analyses were: a training session followed by a method application in a real design change with participants observation. Among other parameters, with the training session it is possible to observe the method's learnability. As Coolican, 2014 mentioned in his book in the chapter Observational Methods – watching and being with people - a researcher makes observation of the participants' reaction times, answers to a questionnaire, memory performance and so on. Observational carries a wide range of meaning in research literature. In a narrow sense it can refer simply to the technique of making observations and this can be used within an experimental design as a measure of a dependent variable. The variables here are learnability, data results convergence after method application and time of this convergence. The application sessions were able to collect the two others variables: about the convergence and its time.

4.4.2.1 First Session: Design for Cabin Safety Method – Training for New Users

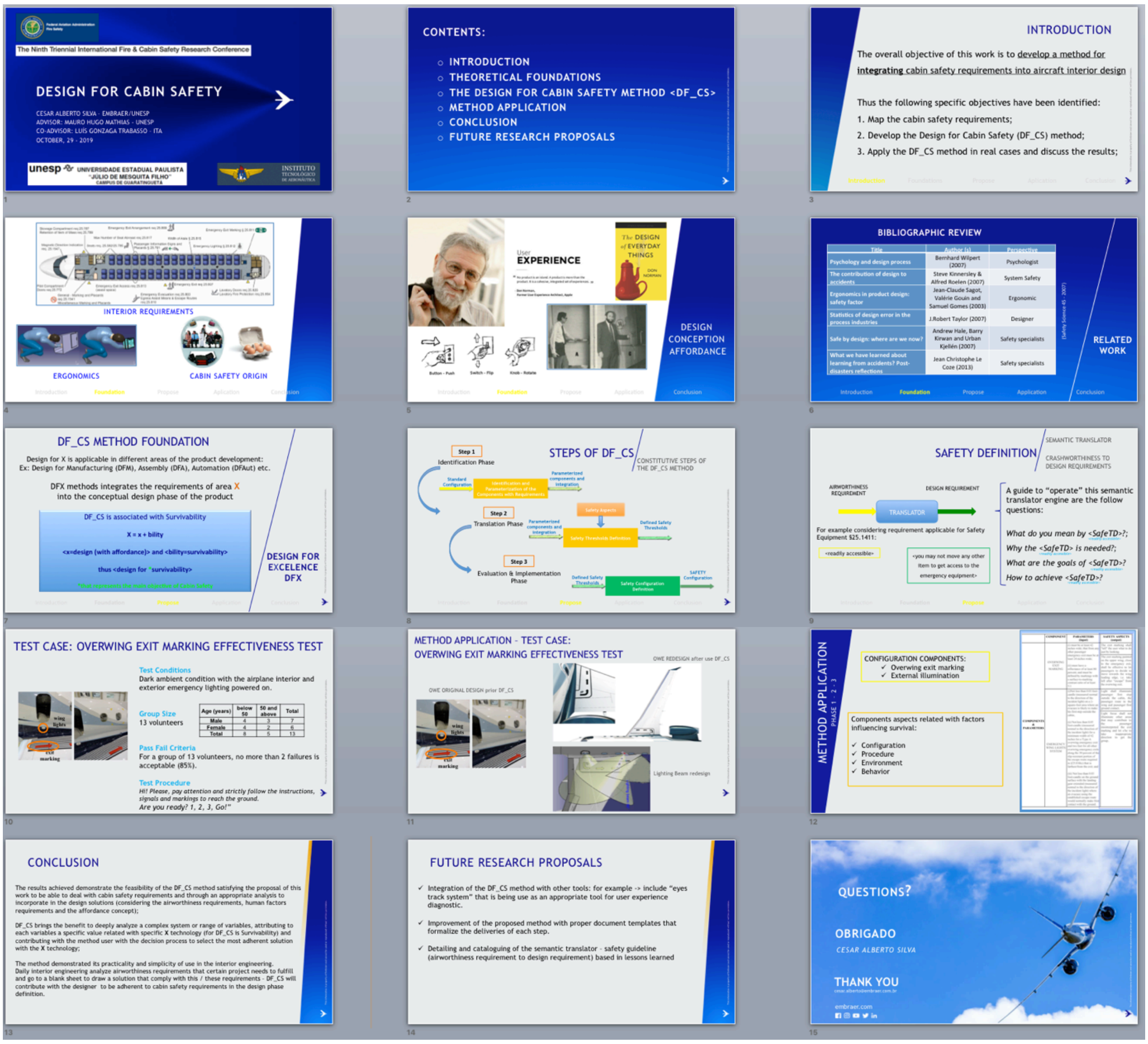
For the training session, a handout was prepared. The contents of this material was summarized in the chapters of this thesis: <chapter 2> theoretical foundations, <chapter 3> Design for Cabin Safety method <DF_CS> and method application <that was one test case of the chapter 4>. The contents provided the participants with the method where the objective is to integrate the requirements of Cabin Safety (preferable) into the conceptual phase of the aircraft interior. The three steps of the method were introduced as: <step 1> for a new interior design they need to identify the changed components and its related and applicable certification requirements,

<step 2> translate these airworthiness requirements into project requirements (highlighting the necessity to identify the safety aspects present in each requirement),

<step 3> identify which are the appropriate means of verification and then prioritize which requirements will actually be applied in the product.

The final material (depicted in Figure 35) was similar to the material presented in the FAA Triennial Seminar about Cabin Safety and Fire (Silva, 2019). Thus, with a presentation with twenty slides and using a few real examples for each method steps, in a session of two and half hours the method was explained.

Figure 35 - DF_CS Method Explanation for New Users

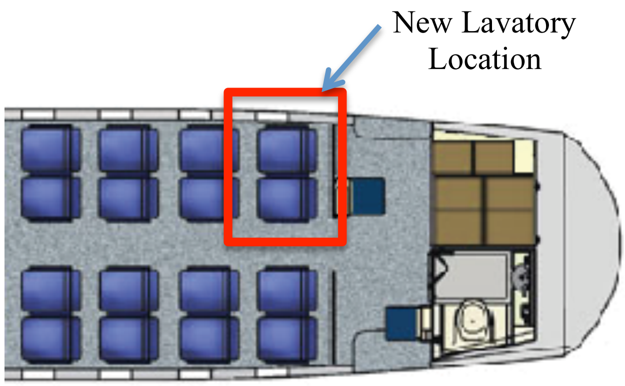


Source: Author (2020).

4.4.2.2 Second Session: Design for Cabin Safety Method – The application of DF_CS in a theoretical case

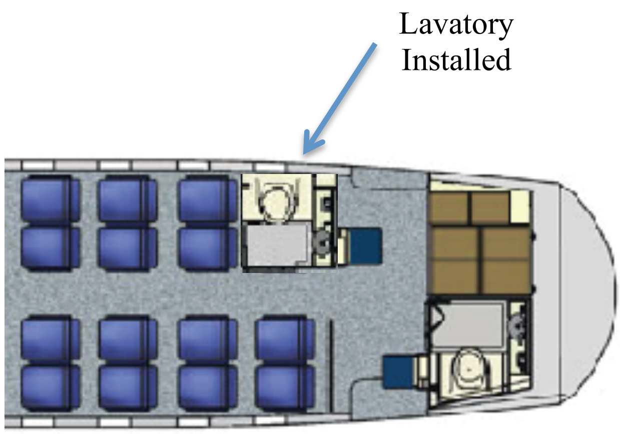
The theoretical case selected was an interior change in a commercial airplane (Embraer 190E2) to design and certify the installation of a new lavatory in the passenger cabin for a specific interior configuration. Using the same interior lay out of Figure 3, Figure 36 and 37 identify the location inside the passenger cabin that the new lavatory will be installed.

Figure 36 – Case Study – New Lavatory Location



Source: Adapted from Embraer Cabin Interior and updated by the author (2020).

Figure 37 – Case Study – New Lavatory Installed



Source: Adapted from Embraer Cabin Interior and updated by the author (2020).

As previously mentioned, the three participants in this case study are Embraer employees and they are familiar with interior configurations used in the products of the company. Figures 36 and 37 were sufficient for them to understand the scope of the work. The exercise was restricted to the Interior Engineering Technology, i.e. did not include interior systems, air management systems and electrical systems.

As the volunteers receive the explanation during the training session <how to operate> the DF_CS method, thus it was required for them to follow the three steps of the method fulfilling the template illustrated in Figure 37:

1) identify in the standard configuration (Figure 36) the components involved in the change, associated requirement(s) for each component, and parameters extracted from the requirements <Step 1>.
2) for each component parameters, they should identify the safety aspects and with the 4 questions to operate the semantic translator engine (as explained in chapter 3): What do you mean by <Safety D>?; Why is <Safety D> needed?; What are the goals of <Safety D>? ;How to achieve <Safety D>?. <Step 2>.
3) lastly, they should prioritize the items that will be part of the safety configuration <Step 3>.

The template adopted to collect the steps output is shown in Figure 38.

Figure 38 - Theoretical Case – Template to Collect Data

Components	Parameters	Safety Aspects	Safety Configuration (adopt/ not adopt)

Source: Author (2020).

4.4.2.3 CASE STUDY TEST RESULTS: Design for Cabin Safety Method – Results collected and overview analysis

As introduced in the context description the case study was conducted to get some evidence about the method application, which are:
- evaluate the method learnability;
- investigate if the method application for different users results in a convergence of data results and
- assess the time used by participants to follow the method and reach the results.

DF_CS Method - Learnability Evaluation

According to Alita Joyce, 2019 (Alita, 2019) from the Nielsen Norman Group in the article How to Measure Learnability of a User Interface "learnability considers how easy it is for users to accomplish a task the first time they encounter the interface and how many repetitions it takes for them to become efficient at that task." In addition, as mentioned by Don Harris in the book Writing Human Factors Research Papers to measure variables in an experimental qualitative case study it is necessary to mention that for some studies the interviewer or observer may require particular knowledge or skills to be able to understand the interviewee's responses and on occasion, probe meaningfully for further detail (Harris, 2012). In these cases, the relevant characteristics of the interviewer should also be included in the manuscript (paper or thesis). Subject matter experts interviewing subject matter experts will help to establish the validity of the interview comments obtained. As one of the variables measured here is learnability, according to Harris, it is relevant to include that this author is a graduated teacher for ten years teaching in a technical high school. Thus with skills to be able to evaluate the training section described in the section 4.4.2.1.

However, through the training section it was observable that the DF_CS method via its three steps and description of each steps, using real examples to explain each step was properly assimilated by the participants during the approximately two hours that it took in this training section. In addition, the observation and results obtained in the next phase of this case study corroborate with this finding.

DF_CS Method – Convergence of data results

Considering the three steps illustrated in Figure 12, the template depicted in Figure 38 to collected, the participants' outputs during the method application.

In the DF_CS method <step 1>, the method user shall identify the components and cabin safety requirements <parameters> associated with the standard configuration. In Table 4.6 it is presented the components and parameters that the three participants extracted from the standard configuration.

Table 4.6 – Components and Paramenters from Participants Case Study

Designer		*Engineer*		*Ergonomist*	
Components	**Parameters**	**Components**	**Parameters**	**Components**	**Parameters**
Lavatory Volume	N/A	Seats	25.785	Lavatory Door	25.820
Dog House / Emergency equipment	25.787 / 25.787	Aisle Width	25.815	Aisle Width	25.815
Seats	25.785	Emergency Equipment	25.1411 / 25.1561	Placards	251.541
Overhead bin / Passenger Service Unit /O2	N/A	Placards	25.1541 / 25.1561 / 25.791	Emergency Equipment	25.1411 / 25.1561
Lavatory door - interference with evacuation path	25.820	Illuminated signs	25.811	Stowage (Dog House)	25.787 / 25.789
Aisle width	25.815	Stowage (Dog House)	25.787 / 25.789	Exit Sign (Illuminated Sign)	25.811
Illuminated signs	25.811	Lavatory	N/A	Proximity Light	25.812
Placards	25.793	Lavatory Door	25.820	Lavatory Floor Protuberance	25.601
Lavatory floor	25.1541 / 25.1561 / 25.791				
Emergency Equipment	25.1411 / 25.1561				

Source: Author (2019) – Extracted from the Participants Template Results.

According to Table 4.6 highlighted in dark green, it is possible to observe that there was a convergence in the results provided by the participants for <step 1> regarding the components and parameters existing in the standard configuration.

Thus, after the convergence in the <step 1>, moved to <step 2 > with the identification of the Safety Aspects for each component/parameter identified in <step 1> and also the translation of each safety aspect into the Safety Aspect Definition. This was consolidated in Table 4.7 by this author collecting the output from all participants.

Table 4.7 – Safety Aspects and its Translations from Participants Case Study

ALL PARTICIPANTS			
Components	**Parameters**	**Safety Aspects**	**Safety Aspects Definition**
Lavatory Door	25.820	Preclude anyone trapped inside lavatory Unlock without special tool	As there is not special tool available at the passenger cabin the lavatory door unlock ought to be performed with hands.
Aisle Width	25.815	Prescriptive Requirement (width = 20")	Not necessary translation.
Placards	251.541	Not be obscured Displayed in a conspicuously place	The placard shall be placed in a way th attracts notice or attention. After defined the placard place it is recommended that the installation shal be validated by test consider small and tall person.
Emergency Equipment	25.1411 / 25.1561	Ready Accessible / Directly Accessible and Location is obvious / Conspicuously Marked / Easily Removable	Do not need to remove anything in fro to get access to the equipment.
Stowage (Dog House)	25.787 / 25.789	=> must be designed for its placarded maximum weight => if the means used is a latched door, the design must consider the wear in service	Install maximum weight placard in all stowage. And perform cycle test to verify the we and tear in service.
Exit Sign (Illuminated Sign)	25.811	Conspicuously Marked	Similar To Placards
Seats	25.785	The elimination of any injurious object within striking radius of the head.	To perform inspection test.
Lavatory Floor Protuberance	25.601	The airplane may not have design features or details that experience has shown to be hazardous or unreliable.	To perform a test with users to evaluat if the protuberance may cause any trapped in the path.

Source: Author (2019) – Extracted from the Participants During Case Study.

The climax of the second section was the translation/conversion of the airworthiness requirements into design requirements plotted in the Table 4.7 in the Safety Aspect Definition column. For that translation, the four questions introduced in Section 3.2.2 were welcomed by the participants. It was observed during the exercise, that the answers for each question generated a productive debate driving users to have a convergence of the results collected in the answers of each one.

To illustrate the debate, we selected the lavatory door, which among others, has a specific requirement:

§25.820 Lavatory doors.

All lavatory doors must be designed to preclude anyone from becoming trapped inside the lavatory. If a locking mechanism is installed, it must be capable of being unlocked from the outside without the aid of special tools

The debate was created by observing the parameter < without the aid of special tools>. Using the four questions for this case, the results was:

Q1: What do you mean by < without the aid of special tools >

A: What is a special tool? Which tools are available inside the passenger cabin during the flight? Is the flight attendant allowed to have tools (like a Swiss army knife)? At the end of the debate they reached the consensus that a tool that is not special and is allowed inside the airplane is the HANDS.

Q2: Why the < without the aid of special tools > is needed?

A: Because there are almost no tools inside the passenger cabin

Q3: What are the goals of < without the aid of special tools >?

A: To release a passenger that for any reason may be locked inside the lavatory

Q4: How to achieve < without the aid of special tools >?

A: Using only hands

The last step regarded how to evaluate the design conception and how to prioritize the safety aspects was also a consensus that the evaluation could be via a cabin safety inspection and all safety aspects should be adopted. The participants mentioned that the method brings to interior engineering a structured way of showing the components of the modification with the relevant aspects for cabin safety technology, and in this way facilitating the debate to gain priority for the implementation of the items in the final configuration.

DF_CS Method – Time used to follow the method and reach the results

The last evidence that we were looking for in the test case analysis was to assess the time used by participants to follow the method and reach a conclusion. The session lasted two hours, and during these two hours the participants followed the method steps and reached the results captured in Table 4.6 and Table 4.7.

It is important to mention that we could spend more time refining results. But as a method evaluation exercise we understand that the time was adequate to go through the whole method with convergence of the collected data.

4.5 SUMMARY

As introduced in Chapter 2, there are cabin requirements that ought to be present in aircraft interior. Chapter 3 illustrates with examples how these requirements may bring subjectivity in the compliance demonstration. In Chapter 4, it is demonstrated that applying the DF_CS method a bridge is constructed to go from a standard to a safety configuration, lowering requirement subjectivity and focusing on what shall be observed to comply with the intent of the requirement. Without a proper method, the task to reach a safety configuration may not be clear and easy to be performed. Sometimes the results will only be discovered when the airplane is assembled and the configuration could be assessed by test.

As demonstrated in Test Case I, if someone compares the Figure 21 marking design in relation to the final designed approved in Figure 22 and Figure 23, independent to the aircraft scenario and also not considering the test conditions, s/he may not identify a significant singular concept that may impose different results when assessed. Without the guidance offered in DF_CS - Step 1, where the designer and safety specialist shall carefully examine the project identifying the relevant aspects of the configuration that ultimately affects positively or negatively the design, different approaches could be taken without good results. One approach could be to only change the arrow color, size or quantity, another could be to increase the light intensity, increase the numbers of spotlights, etc. The DF_CS method guides the user to perform a structured analysis identifying the configuration's relevant components and its parameters, then identify the components integration. For Test Case I, it was observed that it was the combination between arrow format redesign, the addition of the man running pictogram and light cone reposition that ought to be optimum. After step 1, step 2 guides the user to identify the safety aspects for each component with its translation from aeronautical requirement to design requirement. This step is essential to provide the cabin designer the issues that s/he need to focus on in the design to pursue the success for the safety configuration elaboration. Last step in our case, it was easy because the safety aspects were in small numbers and they were all adopted. Therefore, if the case takes several safety aspects the method could facilitate the debate regarding which ones should be adopted.

In Test Case II, the particularity of the method to go deep into the detailed aspects was demonstrated to make a difference in the final results. The method has indicated an analysis in the following components: i) seat occupancy placard, ii) in the installation placard position and iii) in the test procedure and test environment. The parameters (input) and the Safety Aspects (output) that the DF_CS method observed for these three components were specific details that with its observance made the difference in the test performance and consequently in the test results.

In chapter 4.4, it was also attested that when the method was applied by different users (then this author), good results were obtained. A theoretical example of interior configuration change was selected. Participants that work in interior engineering (one ergonomist, one designer and one interior engineer) were selected that received in the first session basic training regarding how the DF_CS method operates and in the second session they were offered one case study to apply the method in the theoretical case.

The Test Results in the chapter 4.4.2.3 demonstrated thru the case study with a project to install a new lavatory inside the passenger cabin that inexperienced people with the DF_CS method can also achieve good results and were benefitted by utilizing the method in daily activities in interior engineering.

These facts attest that the DF_CS method contributed to the success in building a safety configuration, bringing a method to the cabin designer that adheres to the airworthiness requirements in the final cabin design.

5 RESULTS AND CONCLUSION – OVERALL RESEARCH PROGRAM

The overall objective of this work was to develop a method for integrating cabin safety requirements into aircraft interior design leading to produce an interior safety configuration with a shorter development cycle. The method has been developed, detailed and applied at different stages of interior design for passenger transport aircraft. The hypothesis assumed and demonstrated is that executing this method in any phase of the product development, the cabin safety requirements adherence will increase and interior designers and engineers will benefit from using the method. To accomplish this, the following specific objectives were defined and met.

1. Map the cabin safety requirements. The focus on cabin safety requirements in chapter 2 presented that airworthiness requirements define the minimum level of safety applicable to an aeronautical product. Specifically for Cabin Safety, there are dozens of these requirements (Table 2.1 and Figure 3). Some of these requirements are prescriptive requirements providing precise dimensions of features that the product shall have and some are performance-based requirements where each manufacturer ought to create a specific design to demonstrate the compliance with the requirement. As the final user for a cabin interior is the passengers or crew, the aspect related with ergonomics and usability (affordance) are relevant for the design solutions. According to accident investigations that ultimately could result in some new requirements or revisions in existing one, the ergonomic aspects are relevant in normal or emergency conditions to allow proper use of the systems or equipment inside the cabin. Finally, the origin of the Cabin Safety research, also labeled Crashworthiness, research was based on post-crash incident and accident investigations where it was discovered that as much as the cabin safety requirements had adherence for the final interior design, it was possible to increase the survivability after a survivable accident, reducing the injury level of the aircraft occupants allowing them to evacuate the aircraft safely.

2. Develop the Design for Cabin Safety (DF_CS) method. In the bibliographic review and research about cabin safety, it was detected that design plays a significant role in: the prevention of accidents, the cause of accidents, contributing negatively or positively for an accident to happen and, among many other items, as a summary regarding how good or bad the design of a specific feature, system or product that is used for safety can contribute to rescue or to make life harder during a simple or complex accident. Motivated by this review

and with the goal to integrate the requirements of cabin safety, preferably, into the conceptual phase of the aircraft interior design the DF_CS method, was developed in the Chapter 3. The method's roots came from Design For Excellence (DFX) that accord bibliographic review is one of the most effective approaches for Concurrence Engineering that is product development through cooperative teamwork between multiple disciplinary areas during all design phases. Among other methods developed according Design for Excellence aims to improve quality; reduce costs; compress development cycle times; increase flexibility and efficiency. In this work it was also mentioned as similar application, Design for Manufacturing and Design for Automation etc.

The DF_CS method was conceived considering the experience acquired by this author and others interior engineers and designers to find solutions for different projects in different phases of the product development. The generic steps for the method are: ***Step 1***: Identification Phase => *Identification and parameterization of the component with requirement;* ***Step 2***: Translation Phase => *Design Safety definition*; ***Step 3***: Evaluation and Prioritization Phase => *Safety configuration definition*.

The primary benefit of this method is an ideal environment for interior development that includes: firstly, an appropriate analysis regarding which airworthiness requirements are involved in the project under evaluation, secondly which other aspects are involved in the project like factors influencing behavioral responses to emergencies, and ultimately which are the aspects involved in the environment and in the test procedure to attest the safety configuration defined during the method's application. With this tabulated scenario it is possible to increase the chances to incorporate requirements into the design. In this way, as in other similar methods, it is also possible to improve quality, reduce certification costs and compress development cycles times.

3. Apply the DF_CS method in real cases and discuss the results. In chapter 4, the method was applied, results discussed and validated. Two approaches were used:

- Test Cases: the method was applied by this author in two test cases in an actual project for aircraft interior configuration;
- Case Study: the method was explained and tested by different users in an interior design change by one designer, one ergonomist and one engineer (all are from Embraer Interior Engineering Department). The objective to test the method with different users was to collect different opinions about the method, to validate it and also to collect points to be refined or improved.

Each cases that the method was applied was in a different product development phase. Test case I method was applied after a test failure. Test case II method was applied after the interior was installed and it was necessary to comply with a new requirement. The case study method was applied in the development phase of the design change. This demonstrates that it is possible to apply the method to any product development phase. Of course the best way is to apply the method in the early development phase where the costs to modify the project are lower. The method was applied in test case I and II using the interior of a middle executive jet with the maximum capacity of 12 passengers and the case study was applied in a commercial jet with capacity for more than 100 passengers. Also demonstrating that the method ought to be applicable for any interior configuration regardless of the passenger capacity and/or flight mission (i.e. commercial, executive, or defense aviation). Ultimately, the method can be used for any interior component, i.e., for a monument like a galley or a wardrobe, for a curtain/door separating classes, for an emergency exit door, for a new placard, for a new seat model or for a cabin division like first class cabin or passenger cabin.
The good results obtained in the three cases where the method was applied attested that the method brought: quality gains with compressing cycle times to reach a valuable cabin safety solution <due to the passengers understand the safety instructions>, corporative gains <tests were accepted and the configurations were approved by regulatory authorities> and academic and industrial gains <a method was elaborated and tested and it is operational for future use>. In addition, the DF_CS method brings the benefit to analyze a complex system, attributing to each component a specific significance related with survivability, contributing to select the most adherent solution for cabin safety. As mentioned in Chapter 4, without a proper method, the interior engineering would start a new white paper design solution which the requirements could be evaluated only after the aircraft interior was installed.

4. Identify opportunities for improvement in cabin safety. The identified opportunity to improve cabin safety was the creation of the method. What was observed before having a method is that the interior development process takes place in a very personal way and based on the experience of each professional. If it is a small change, it goes straight to the catia in search of solutions. If it is a new configuration, a project review is made to identify the more specific details. There is therefore a methodological shortcoming to follow that is a systematic way of evaluating the components that make up the modification or the new configuration, within the requirements of these components that are the parameters that must be present in the final product and how to translate these parameters from the requirements to design

parameters and finally evaluate and test the final product. As stated above, the opportunity identified was the elaboration of the method. This brings a structured way of three steps where the method brings the benefit to deeply analyze a complex system or range of variables, attributing to each variable a specific significance related with specific X technology (for DF_CS is Survivability) and helping the method user with the decision process to select the most adherent solution with the X technology.

Besides its practicality, the DF_CS method demonstrated its utility to contribute with the designer and the cabin safety specialist into a IPD environment to have facts and data that demonstrated that the adoption of some Safety D in the final product could be more/less adherent to the airworthiness requirement. Contributing in this way with the design decision process helped to build a safe cabin modification or new configuration.

During this research, similar methods/applications were analyzed. They were developed adopting the same methodology of DFX: design for automation within the aeronautical domain (Silva, 2017), design for civil construction safety (Silva, 2016), design for additive manufacturing method of direct metal lightweight parts (Cruz, 2017). These similar applications have the benefit to deeply analyze a complex system or range of variables in common with DF_CS.

Finally, the method demonstrated its practicality and simplicity of use allowing the interior engineer a new opportunity through the DF_CS method to contribute to the day-to-day results of this department.

5.1 CONSIDERATIONS FOR FUTURE RESEARCHES

The DF_CS method has generic qualitative approaches with its theoretical position explicitly to seek to improve survivability in interior cabin design. This method has similarities with others DFX methods, however the X here is completely unique.

This research has limitations related with it, for example the translation of the airworthiness requirement for design requirements. It was not provide in this work translation for all cabin safety requirements. In Chapter 4, it was translated the requirements involved in the three cases that were analyzed. In Chapter 3 Table 3.4, there are some interior requirements presented where in the requirement language there appear some subjective terms that translation to design requirements may impose some difficulties to the designer: this translation could be the object of future research updating this table with all the requirements and adding a column where the safety aspects for each subjective term will have its translation.

Another limitation is related to the human factor aspect that has influence in each specific cabin area or operational procedure. For example, a complex and demanding area for interior cabin design is the over wing emergency exit. Every aspect that must be drawn for this area is extremely scrutinized by the regulatory agencies and the compliance demonstration for the requirements is obtained from different test cases involving volunteers. There are tests with emergency light conditions, opening the exit from inside and outside, test simulation with a crowd surrounding the exit and the volunteer is required to open the hatch, tests involving short woman percentile, etc. The implementation of DF_CS for this cabin segment could be a significant expansion of this method functionality for interior engineering.

Considering the expansion of this method functionality could be considered the integration of this DF_CS method with other technologies. For example, the use of "eyes track system" that is being used as an appropriate tool for user experience diagnostic (Hsu Y. et al, 2013). Tracking people's eye movements provide an insight into mental imagery and display-based information processing, which could enhance the comprehensibility regarding the design affordance that the interior features ought to have.

Ultimately, all technology that compound an aircraft system could have its own design for (DF) method providing to IPD meeting a uniform methodology to assess a new product or a significant change in a specific type certificate.

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