A method to obtain context based DFE criteria lists applicable to the development of friendly recycling composite aeronautic structures

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Abstract: At the same pace that more and more attention is given to environmental issues associated to the end of life of manufactured goods, the disposal of aircrafts at the end of their useful life is increasingly perceived as a problem that deserves attention, since the current general practice is still to dispose the retired aircrafts in 'cemeteries' around the globe. This problem has become even more critical with the growing trend of composite materials use in aeronautical structures, whose disposal and/or recycling processes are still complex, with few practical solutions. In the research study described in this paper, a method for developing contextual DFE criteria lists is proposed. It can be applied to the initial phases of the product development process and it might help the designers develop aircraft structures that are easier to be recycled or disposed at the end of their life cycle. The method is validated by comparing the resultant design of two similar aircraft critical structural parts, one of them was developed considering a criteria list deployed as from the proposed method, in relation to their disposability. The results demonstrated that the proposed DFE list increased the disposability of the component by not allowing the use of certain design solutions that cannot be easily recycled with the currently available recycling methods.

Keywords: design for environment, aircraft structures, composite materials

1. Introduction

At some stage an aircraft will be taken out of service. Indeed, as any other product, it depreciates with time and eventually its operational cost becomes uneconomic. A recent report from Airbus (2008) shows that an average of 150 commercial jetliners are retiring each year worldwide. Nevertheless, it is only at this point along the long life cycle of an aircraft that the issue of how to dispose this aircraft typically arises. Until a few years ago, at the end of their lives, airplanes were simply abandoned at deserts or stored beside certain airports around the globe. In some cases, part of their systems are removed and recycled, but the airframes were basically just left to slowly degrade during outdoor storage.

With the increasing environmental awareness of the general public in regard to the discard and disposal of manufactured goods, this situation has become a problem. For the manufacturer, for instance, this may imply corporate mark issues, since the airframe is, most of the times, still easily recognizable as its own airframe. In a world where corporate identity and brand awareness has significant commercial value and importance, there is a growing reluctance for the manufacturers to be associated with decaying structures (NETWORK..., 2007).

In a more modern approach, after all valuable components and systems are removed, the remaining fuselage is broken down into small pieces and processed by a metal recovery company. This is somehow a reasonable solution for the discard of most aircrafts now entering the end of their life cycles, since their structures are basically manufactured of aluminum. Nonetheless, as aircraft manufacturers increase the composite content of commercial aircrafts, the recycling of these structures becomes increasingly difficult, since the disposal of this kind of materials is a new technical issue and there are a number of challenges to overcome. Indeed, the ever increasing use of composite material in aeronautics structures results in larger amounts of waste, be it in the form of manufacturing waste (current issue), but also in the future, when the time comes to discard these aircrafts.

Besides, not only are legislations regarding composite materials getting tougher, especially in Europe (HEDLUND-ÅSTRÖM; LUTTROPP, 2006), but also it is believed that, in the near future, international laws will force aircraft's manufacturers and suppliers to take responsibility for disposing and/or recycling the waste generated by the end of their products life cycle, as has occurred with vehicle manufacturers after the introduction of End of Life Vehicles (ELVs) Directive 2000/53/EC in Europe (THE EUROPEAN... ,2000). Although there are no similar guidelines applied to the aviation industry, there is a consensus in this industry that a similar regulation could be introduced soon. Thus, nowadays the planning of the end-of-life has become a new and important issue for the manufacturer of aeronautic structures, both regarding the currently aging fleet, as well as the new planes under current development.

In order to better understand and try to solve the issues raised above, aircraft manufacturers and various companies in the aeronautical sector are joining efforts in environmental related projects, and considering the establishment of centers where aircrafts can be stored and maintained properly to get back into service or be discarded in a economic manner, meeting the required environmental practices. Two of these initiatives are PAMELA (Process for Advanced Management of End of Life Aircraft) and AFRA (Aircraft Fleet Recycling Association) programs (PAMELA LIFE, 2009; AIRCRAFT..., 2006).

Together with the efforts to give a retired airplane an environmental friendly destination (focused on the currently fleet), a different approach (focused on the next generation of airplanes) is to design this product so that it can be easily discarded/recycled at the end of its useful life. This is attained by applying a Design for Environment (DFE) approach along the aircraft's product development (PD) process. A DFE approach, on the other hand, can only be implemented by means of applying the appropriate DFE methods and tools for the product under development, at the right time of the PD process. The problem, in this case, is that there are no DFE methods and tools directly applicable to the development of aircraft composite structures. Whereas the lack of such tools form the motivation to the research work described in here, the actual development and validation of a solution to this problem composes its scope.

2. Proposed approach

Thoughtfulness along the development of new design methods, tools and approaches for a given situation is quite relevant and can make all the difference between the resultant solution being adopted by practitioners (the desired situation) or just being relegated to the library's shelf (ARAUJO, 2001). According to Araujo (2001), aspects such as usability, which encourages their adoption in practice, aren't generally given the right amount of thought by most developers, what helps to explain the low degree of adoption of design methodology in practice (ARAUJO, 2001). Yet, according to Ritzen (2000 apud LINDAHL, 2005), the usage of methods and tools only becomes a regular activity if they support the user, in the case, designers, with their own work. Moreover, the success of a method or tool depends not only on the method or tool itself, but also the context which it is used. Thus, the correct use of a tool is of paramount importance to achieve significant results.

The present body of research on Product Development in general, and on Design for Environment in particular, shows a large variety of classes of DFE approaches that have been developed and tested. In this paper we focus on DFE checklists and guidelines as an attempt to obtain a simple and robust solution to help product developers adopt DFE practices.

A large number of general DFE checklists and guidelines exist in literature, described for instance by Graedel and Allenby (1998), Brezet and van Hemel (1997), Gertsakis et al. (1997 apud LINDAHL, 2000), Magnusson (1997 apud LINDAHL, 2000), Luttropp and Lagerstedt (2006). Only a few authors, such as Poledna (2008), developed guidelines to be used in the development of specific types of products: furniture, in this case. Thus, due to the general lack of specific DFE solutions to specific sectors, some large companies, as Bombardier, have developed their own tools to meet internal specific demands, which included a whole DFE chapter (with tools and methods) into their Engineering Book of Knowledge, available on its intranet (LUTTROPP; LAGERSTEDT, 2006).

In this scenario the primary objective of the work described in this paper was to develop and apply a method to allow the derivation of context based DFE criteria lists that can be applied to the initial phases of the development of aeronautic composite structures. The choice for DFE criteria lists as the output of this method, instead of more sophisticated classes of tools and methods, is mainly due to the fact that they are self-explanatory (easy to understand) and do not require the use of software or user training, which facilitates their incorporation into the designers everyday development activities.

It's worth noting that the focus and the applicability of the proposed solution is on the development of primary composite structures for aeronautic use. It is known that aeronautics manufacturing industry has a complex PD process, in special due to the large amount of requirements and standards regulating this sector (ARAUJO; CRUZ, 2000). Thus, the proposed approach format as being a list of criteria could be incorporated into the current aircraft PD process without adding large workload either on practitioners or PD support personal. Furthermore, the list of criteria format allows incorporating new information quite easily, being flexible and updated, what is essential.

3. Method development and application

3.1. The method for obtaining a DFE criteria list

This section presents a method developed to systematically obtain a list of context based DFE criteria to be used on design of composite aircraft structures. It is expected that the adoption and implementation of the DFE list by the design team will yield structures easier to be recycled or discarded at the end of its useful life cycle.

The proposed method seeks a way to obtain and analyze the information necessary to generate a list of criteria for the parts design by analyzing different aspects of the end of its life cycle. The method is depicted in Figure 1, and is based on the investigation of three key parameters: a) structures disposal, b) used materials and c) parts design.

The proposed method is detailed as follows.

3.2. Establishing a list of criteria for development of primary parts in composite materials

DI.1: Analysis of available discard/recycling processes and procedures: This step requires the involved parties to search and list the processes currently available, or in development, for the discard/recycling of the materials and solutions that will be applied in the product. In composite aeronautics applications, the focus of this paper, reinforced carbon fiber composites are the most widely used material and this information has directed this research on the available disposal/recycling techniques. There are several composite disposal methods in development, as reuse (HEDLUND-ASTRÖM, 2005), mechanical material recycling (PICKERING, 2006; ASSOCIAÇÃO..., 2008), chemical recycling (BUGGY; FARRAGH; MADDEN, 1995; LIU et al., 2004; NETWORK..., 2007; PIÑERO-HERNANZ et al., 2008; BAI; WANG; FENG,, 2010; MARSH, 2009; HYDE et al, 2006) and thermal processes like pyrolysis (MARCO et al., 2002; WILLIAMS et al., 2005; CUNLIFFE et al., 2003; ADHERENT TECHNOLOGIES, 2008; RECYCLED CARBON FIBRE LTD, 2010), fluidized-bed process (PICKERING et al., 2000; YIP et al., 2002; PICKERING, 2006) and incineration (CONROY et al., 2006; ASSOCIAÇÃO..., 2008; HEDLUND-ASTRÖM, 2005; BOEING, 2003).

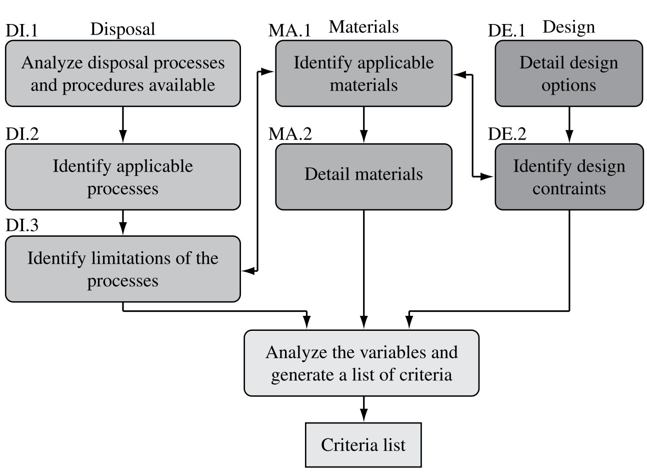

Figure 1. Method for formulating a list of criteria DFE/Composite.

The output of this step is a list of available disposal/recycling processes, together with their description, characteristics etc.

DI.2: Select the applicable processes: After completing the prior analysis of the available disposal/recycling processes, it is now necessary to select the most suitable for the particular case that is being analyzed. This step assess the most likely recycling or disposal process by which the composite structure being developed will undergo when it reaches the end of its useful life.

Thus, it is possible to evaluate, based on certain characteristics that are discussed below, what would be the most appropriate or applicable processes in any particular case in order to further investigate them and even guide the achievement of the criteria list for an adequate designed part that suits all requirements of a particular disposal process. A number of factors can be used to evaluate the applicability of a particular process, depending on the characteristics of the aeronautical company, including its geographical location and consumer market.

One relevant factor, for instance, is the law of the country or region in which the discard will supposedly take place. For example, the prohibition of certain substances or the establishment of air emission limits restricts the variety of materials that the industry under this law may accept for processing (its raw material). Therefore, it is important to consider the laws applicable in the country(ies) in which an aircraft company wants to make the aircraft suitable to be properly disposed, since it influences the choices of materials and design options of a component in development. The maturity of the technical and productive capacity of the recycling process must also be evaluated. Thus, the selected recycling processes ought to be able to handle the estimated volume of material that is discarded by a particular type of product developed.

Other process information, whenever available, should be taken into account to evaluate the disposal options, such as energy consumption and characteristics of the waste generated during the process. Eco-indicators, such as eco-indicator 99 (GOEDKOOP et al., 2000), can also be used to compare and assess options for disposal, if available.

The location of the industries that will recycle/dispose the parts is also a factor to be considered, since, depending on the technique employed in the process, it is possible that only a very few companies could eventually carry out the service. As a consequence, end of life parts logistics issues may also need to be discussed.

Based on the information collected on disposal processes, it was found that many of them are still at laboratory scale, while others are in the pilot process stage. In other words, they lack of technological maturity. When searching for a viable recycling process to be adopted at the end of components lives, it is worth considering that these processes should have a high level of maturity.

Accordingly, there is a strong tendency in today's aerospace industry to recycle its parts with carbon fiber composites through the pyrolysis process, because this is the technique that currently seems to be more economically viable, since it is possible to recover the fibers, which have high added value. Because of that it has received major investments in research and development. One UK based company has already launched its composite recycling plant. Other recycling plants which apply this technique are also being established in different countries

The output of this step is a list of selected recycling process(es).

DI.3: Identify methods/process limitations: This step aims to identify the peculiarities of the technique and process(es) selected in the previous step, as well the possible limitations associated to them and that can create restrictions to the design options or choice of materials.

As the development of composite recycling processes is recent and still being implemented, much information about them is not available. It is known that, regardless the technique, it is necessary to know the input stream composition (in this case, material composition of the parts to be recycled/disposed) to adjust the operational parameters of the chemical plant. Thus, it is essential to identify the constituent components of the parts that are the object of the study. There are also some substances that must not be present on components that will be thermally processed because they produce toxic emissions, such as halogens. By analyzing the pyrolysis process, it is concluded, for instance, that there are still difficulties in processing rigid foam and honeycomb.

The output of this step is a list of limitations pertaining to applicable recycling technique(s) and procedures.

MA.1: Identify the applicable materials: In this step, a generic list of materials used in the applications of interest (that is, the structure being developed) will be elaborated, covering both standard use and new concepts, as well as categories of substances that are frequently incorporated into the materials and may influence the recycling, such as surface treatment, adhesives, inserts, and so on. The most important materials initially identified usually guide the research on the disposal processes available.

Within the broad range of polymeric-matrix composites available, it was found that those with carbon fiber as reinforcement are the most common among primary structures on aircrafts because of their properties, and the resin most widely used as matrix is epoxy. Besides fiber and resin, a composite material can have other components such as foam, honeycombs, additives and substances incorporated due to the surface treatment processes.

The output of this step is a generic list of applicable materials to the parts being developed.

MA.2 Materials detailing: In this step the types or material categories listed in the previous item are detailed as follows.

MA2.1: Composites: This paper focuses on the analysis of composites with carbon fiber and epoxy resin. They are manufactured through the use of prepregs. The technology for manufacturing prepregs is controlled by a few suppliers (COSTA et al., 2003), due to the resin formulations, which seek to meet specific needs in terms of mechanical properties of the final composite (finished product). The access to information about resin technology (formulations, additives and preparation conditions) is, therefore, very limited, representing an important limitation for this method.

MA2.2: Coatings: aircraft parts receive coatings and the aircraft is painted and personalized for each client. It basically consists of applying a primer to waterproof, remove porosity and promote good paint adhesion. Whenever necessary, it is applied a polyester mass for filling in large pores in the material. After the primer, the painting and finishing coats are thus applied. All of them act as barriers against water, ultraviolet light and corrosion. In terms of raw materials, primers are based either on epoxy or polyurethane. Paints are generally polyurethane, basically because it is durable, chemically resistant and gives the surface a high gloss finish. Additives are used to render many different characteristics such as corrosion inhibitors, fungicides, UV protection, among others. Each coating is unique in its composition and manufacturing process.

The outputs of this step are the details of the materials identified in the previous step.

DE.1: Detail design options: For each part or structure being designed it is common to have different alternatives of material and construction types, as well as design concepts. The analysis of these options impacts the recycling criteria list. The design options should be detailed down to a level in which the applicable materials of the parts that are object of study can be evident.

Some of the usual design options refer to structure and assembly as detailed below.

Structure: Cores can be incorporated into composite parts to provide structural rigidity without significantly penalizing weight. Solid laminates are made without cores. Core materials can be made of honeycomb or rigid foam.

The mostly applied honeycombs are Nomex®, an aramid based material developed by the DuPont company. Nomex® honeycombs are fire resistant, flexible, lightweight and have good impact resistance. There are several types of rigid foams. The usually used is Rohacell® from Evonik Industries AG, which is based on polymethacrylimide (PMI).

Assembly: In manufacturing composite structures, parts are produced as single blocks; there are no joints or connections from different parts of composites to form certain structure, as each piece can be manufactured as a single party. Thus, a need that arises from this approach is the union of different parts, highlighting the composite-metal junction. To do this, it is necessary to use metal inserts in composite parts whose basic purpose is to support the loads from the fasteners. (The assembly is done by mechanical fasteners such as rivets because the certifying authority is not usually prone to approve adhesives joints).

The output of this step is a list of design options available for a given structure.

DE.2: Identify the design constraints: Some types of constraints are inherent to the component design because of the purpose of the component or the location and/or environment planned for its installation. It is necessary to identify on the component design if there are and what are the types of such restrictions.

It may be necessary, for instance, to incorporate metallic screens (usually copper) in the composite structure, depending on which aircraft parts would be constructed of such material and on aircraft lightning protection design.

The output of this step is a list of identified design constraints.

Final Step: Analyze the variables and generate the customized DFE criteria list: This is the final step of data consolidation, and the derivation of the DFE criteria list to be used during the product development process. The project most striking variables considered are evaluated:

1. Composite material: The aviation industry uses prepregs as raw material for composite manufacture, which hinders access to information on the resin formulations (although buyers receive MSDS – Material Safety Data Sheet), with no information about which types of additives are incorporated and whether some of these additives would be toxic or undesirable to the recycling process of a discarded part. The specification of the substances types which are not expected to be present in purchased prepregs may mean developing a new material by the supplier to comply with the client requirements.
2. Additives: The main concern regarding the additives applied to composite structures materials are those used as fire retardants as they may encumber or impair the processing of these materials. The situation is worse with those containing additives such as antimony and brominated substances, since they produce toxic substances after processing – bromine, for example, produces smoke containing hydrobromic acid, which is toxic and corrosive. Larger infrastructure would be necessary to discard the parts containing these additives, with the use of scrubbers for the waste treatment, which represents a disposal problem for any residual liquor of the washing. This increases capital costs of investment in recycling plant and makes it difficult to comply with environmental constraints.
3. Structures: It was found that honeycomb and rigid foams end-of-life processing current techniques are still problematic (RECYCLED CARBON FIBRE, 2010). There are also environmental implications in the discard of these structures, since they decompose only partially during pyrolysis process, generating emissions and a solid residue that is problematic to discard. Metallic screens are another issue to be considered during DFE design: depending on which aircraft parts would be made of composites, the screens could be very large, to the point of being completely embedded in the composite, which encumbers the material separation by a simple and economically feasible method. Some of surveyed disposal techniques claim to support metal contaminants in their process, but these were tested with metal inserts that can be easily removed and, comparatively, with small amount of metal present compared to the composite to be processed. Thus, there is still no information about the behavior of this type of structure during processing by the methods surveyed.
4. Dismantling: It is necessary to separate the parts made of composite materials from those made of other materials and route them to the appropriate disposal channels. There are two types of disassembly: destructive and nondestructive. Nondestructive disassembly is the process of systematic removal of desirable parts, preserving them from damage caused by the disassembly process. This avoids contamination by other types of materials present in the adjacent structures. Hazardous substances must not be present in material for recycling. The processes of dismantling and decommissioning can be done more effectively if the person responsible for these steps has information about hazardous content and metallic inserts. This can also result in a safe environment working and high quality recycled material. As a DFE guideline, the project must ensure the system can be disassembled with a minimum cost and effort. This is an important requirement for end of life considerations, such as separation and recycling of components.

5. Identification: Proper identification of different types of materials in structures facilitates the substances separation process of the parts. In the case of some substances, to make this identification visually is simply not feasible, especially after surface treatments and paints have been applied. Several techniques are employed when there is no such information, like infrared spectrometry and X-rays (HENDRIX, 1996). Properly identifying the materials, and then get them apart, are issues of paramount importance when it comes to recycling and disposal. Some studies (HEDLUND-ÅSTRÖM, 2005; HEDLUND-ÅSTRÖM; LUTTROPP, 2006; DAVIDSON, 2010) have discussed system for identifying or marking pattern for composite parts to be placed in the piece itself, containing, at least, information about types of matrix resins and fibers used. The legislation for the aviation industry is extremely rigorous and all parts must be traceable. Information on all structures and materials are available on the manufacturer, but may not be available for the final client. The provision of information (at least basic ones) directly on the parts would be a pathway to increase the odds that it would find its way into proper disposal, and even facilitates the material separation during dismantling process of aircraft.

The output of this step is a list of DFE criteria customized to the type of structure being designed.

3.2.1. List of criteria – results from the proposed method application

After analyzing the recycling processes and design variables in the previous sections, it is possible to see the criteria derived from them. This criteria is shown below in Table 1.

4. Applying the derived DFE criteria list: evaluating an aircraft structure design

In order to illustrate a situation where the application of the DFE criteria list generated above would have lead to a superior design solution in terms of disposability of the developed part at the end of its life, two composite pressure bulkhead conceptual studies of a small aircraft from an aerospace company were analyzed.

The back pressure bulkhead is a structure located at the fuselage rear whose function is to isolate the pressurized cabin area from the region of the cone tail, which is not pressurized. The pressure bulkhead design depends on aircraft size, space, weight and systems involved. This may present different shapes: flat, hemispherical and elliptical cap (CASAGRANDE, 2003).

In the first case evaluated, the pressure bulkhead was designed using carbon-fiber epoxy resin prepregs on the inner skin and aramid based honeycomb on core. For the second structure it was designed to be laminated using carbon-fiber epoxy resin prepregs. Both structures have been or are being developed following the traditional product development process adopted by the company (ARAUJO; CRUZ, 2000).

The comparison between the two projects resulted in the following findings: They have functional equivalence and it is known that the first was developed using honeycomb structure, while the second used solid laminated composites exclusively. By comparing these design decisions in the light of the list of DFE criteria proposed in the previous section, it appears that the first design option, which uses honeycomb structures, could not be properly disposed by the pyrolysis process currently available. Thus, if no new recycling process that can process composite parts which include honeycomb cores are developed along the next

Table 1. List of criteria to be used during aeronautic composite structures development.

Criteria list to be used during composite material structures development	
Criteria	**Justification/Rationale**
Avoid the use of cores – honeycomb and rigid foam	With current technology, these structures still can not be processed.
Avoid the use of flame retardants, whenever possible	By the very function performed, it inhibits the composite processing by techniques that use temperature as agent.
Do not use flame retardant phosphorus derivatives	Environmental problems while processing the waste. Phosphorus derivatives generate phosphine during processing, which is toxic and dangerous to the environment.
Use paints and surface treatments only when absolutely necessary	This avoids the introduction of contaminating materials into the system. Many paints contain substances that prevent the material processing.
Do not use substances containing heavy metals	Environmental problems while processing the waste. Example: Some anti-corrosion coatings have hexavalent chromium in its formulation.
Do not use substances containing halogens (bromine, chlorine, fluorine etc.)	Environmental problems during waste processing. Example: brominated compounds are widely used as anti-flame additives; it is known that dioxins are byproducts of many industrial processes where chlorine and chemicals derived from it are produced, used and disposed.

decade or two, this part will simply not be recycled at the end of their life cycle. Based on the list of criteria elaborated, it appears that the second project has characteristics that facilitate its disposal, and the structures eventually produced can be recycled by pyrolysis technology available today. It can be concluded – for this case study – that the adoption of the criteria list as an auxiliary tool in the design of such structures can support final design decisions from an environmental standpoint.

5. Discussion on the proposed method application

Given the difficulty in obtaining information about peculiarities and obstacles currently encountered in processing large-scale end-of-life parts made of composite materials, and even the lack of response from scientific community for some issues, the developed DFE list is seen merely as a reference tool that could guide practitioners involved in the design of composite aeronautics structures, but they must not fail to keep up with innovations and changes in this area that has only recently begun to develop. Indeed, this list is a preliminary criteria list built with the data obtained and it should expand as information available increase, undergoing changes and updates to adapt to the changing technology of composite disposal and environmental laws.

The literature mentions as an advantage of the pyrolysis process the fact that all products can be recovered and reused in one form or another, and the resulting liquid fraction could be used directly as fuel or added to the raw materials from refineries oil, possible to be an important source of chemicals. However, no studies were found regarding the liquid fraction composition and also about what kind of impurities would be present. This information is crucial due to the fact that no chemical industry would accept to contaminate the reactor with an input content of indeterminate composition and without some degree of purity required for its process. The whole idea of the process is to properly dispose the materials. Nevertheless, if during the recycling process it generates wastes that can damage the environment more than the material itself, then the whole process loses its point. These aspects need to be carefully analyzed and need to be further investigated by the academia.

Another group of aspects to be analyzed are the characteristics and limitations of each reactor used by the recycling companies, as these can generate important DFE criteria to be incorporated early in the product development process. This is also very important since recycling companies are unlikely to accept raw material parts containing harmful substances to its reactor. Thus, the components that do not contain harmful substances to the operation of the reactor would be important, besides the fact that this does not cause environmental impact.

It is noteworthy this list presented in the section 3 was developed based on available data of today's technology, to be used in the development of aircraft parts that will be discarded only in 10 or 20 years. It is reasonable to expect that on this period much will improve.

6. Conclusions

Analysis of the available Design for Environment literature showed the existence of many DFE methods and tools of general application, but revealed the lack of specific tools applicable specifically to the development of aircraft composite structures friendly discard. From the information gathered from the literature, it was proposed a method for developing a context based on DFE criteria list that can be applied to the initial development phases of composite structures, and that can lead to design solutions that are easier to be recycled or discarded at the end of their life cycle.

In order to test the method, it was run considering the present technological scenario, by means of which a simplified DFE criteria list was derived and applied to analyzing the designs of two rear pressure bulkheads. This analysis showed with little room for doubts the potential of the criteria list application in delivering structures that have a higher degree of friendship in regard to their potential of being recycled with the currently available processes.

In regard to the application of the method, which was the focus of the research, the main difficulty was to obtain information, especially regarding the available composite recycling processes, both because this whole field of research is quite new, and because the subject is perceived as a strategic issue by the companies currently funding this type of studies.

All of this limited the access to information about the processes characteristics, peculiarities and limitations which, by their turn, are the most relevant information when trying to build a useful list of DFE criteria. In spite of that, the method was run and an initial DFE criteria list was derived.

The generated contextual DFE list suggests, among other things, not using rigid foams and honeycombs as project solutions. Considering today´s available technical solutions, it may not always be possible. However, as aircraft manufacturers start to adopt DFE into their PD process, arisen from the need to properly dispose the aircraft structures at the end of their useful lives, coupled with the extensive knowledge that the ongoing research for the development of new recycling processes shall bring, and also coupled with the emergence of new materials, it will certainly be possible to improve the materials and the DFE criteria list developed for composite aircraft structures.

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