

Defining Environmental Indicators at Detail Design Stage as Part of an Ecodesign Strategy

Greg Doudrich, Guillaume Corriveau, Denis Walch, Kahina Oudjehani, and Franck Dervault
Bombardier Aerospace

ABSTRACT

Implementing Design for Environment (DfE) into the design process requires a strategic integration. Furthermore, as DfE is continuously evolving, flexible processes need to be implemented. This article focuses on the integration of DfE into an optimization framework with the objective of influencing next-generation aircraft. For this purpose, DfE and Structures groups are developing together a set of new environmental indicators covering all life cycle stages of the product by coupling a list of yes/no questions with an environmental matrix. The following indicators are calculated: Regulation risk, Impact of manufacturing the part, CO₂ emissions and Recyclability potential. These indicators will be used as constraints in the multi-disciplinary design optimization (MDO) framework, meaning that the structure will be designed while complying with environmental targets and anticipating future regulation changes. To illustrate this new methodology, it is applied to three common processes used in structural design on a generic part: aluminum with chemical milling, aluminum with mechanical milling and composite produced by automated fiber placement process. Through this initiative, it is believed that in the mid-term, manufacturing processes selection will not only be influenced by technical and cost requirements, but also considering their environmental impacts.

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1. INTRODUCTION

1.1. Context in Aviation

In response to increasing awareness from customers and international organizations on its environmental impact, the aerospace industry has set ambitious objectives to protect its promising future. One of the goals that have been put forward is to reach a carbon neutral growth by 2020 and to reduce CO₂ emissions by 50% in 2050 at worldwide fleet level [1]. In parallel, more and more regulations such as REACH (Registration, Evaluation, Authorization and restriction of Chemicals) in Europe, are restricting or banning the use of chemicals in products because of their potential hazard on health and/or environment and are forcing companies to track them in their product [2].

As part of this industry, Bombardier is fully involved in this initiative and decided to go further by implementing a design for environment (DfE) strategy (also called eco-design) based on ISO14062 definition as the "integration of environmental aspects into product design and development" [3].

The aim of this paper is to provide one of the initiatives pursued internally within this long-term goal by defining and integrating environmental indicators within a design optimization framework. As a first step, the article will specifically focus on airframe design.

1.2. Implementation Challenges

In order to be effective, DfE must be taken into account as early as possible in the product development strategy. In fact, more than 80% of environmental impacts are determined at early design stage [4]. Furthermore, ISO14062 recommends planification and conceptual design as the most relevant phases for an efficient implementation of DfE (see [Figure 1](#)) [3].

However, the main challenge related to this early integration is data availability as all product features (materials, manufacturing processes...) cannot be obtained or even defined at this point in the development process. This kind of data is only available at later stages (starting with detail design). On the other hand, as development process evolves, the designer's ability to reduce the environmental impact decreases. This phenomenon is known as the

ecodesign paradox concept and has been discussed by several authors, as shown on [Figure 1](#) [5, 6]. It well illustrates the fact that implementing ecodesign at each step of the product development is crucial and that the supporting tools shall find the right trade-off between relevant results and data inputs available.

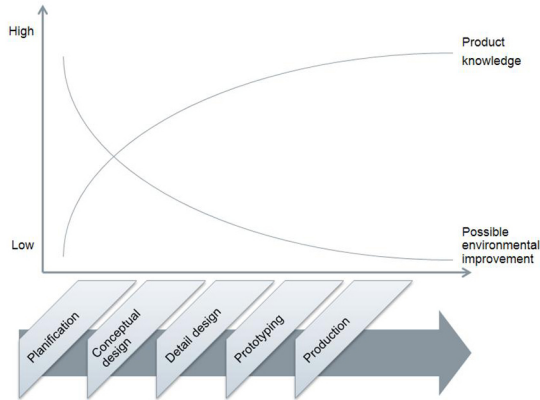


Figure 1. Ecodesign paradox concept throughout the product development process [7]

Moreover, the proposed solution shall be flexible, adaptable and shall be integrated in existing tools/processes rather than bringing any new standalone framework. Results also need to be easily understood by structure engineers which usually do not have a thorough knowledge of environmental challenges [6].

In the context of this article, the objective is to develop a methodology for preliminary integration of environmental indicators at detail design phase. At this stage, product knowledge is sufficient enough to influence materials and manufacturing processes' selection, meaning that there is still room for environmental improvement (as shown on [Figure 1](#)).

1.3. Review of Existing Tools

In order to implement efficiently an ecodesign strategy, a great number of authors have already developed solutions having the intent to help engineers in their approach. As can be seen on [Figure 2](#), these solutions can be grouped in categories and ranked based on two key characteristics [8]:

- **Relevancy of environmental evaluation:** this parameter looks at how, quantitatively or qualitatively, the tool is able to assess environmental impact on the whole life cycle of a product with a reduced uncertainty.
- **Potential of environmental improvement:** this parameter looks at how the tool allows optimizing the aircraft design in order to reduce the environmental footprint of the product.

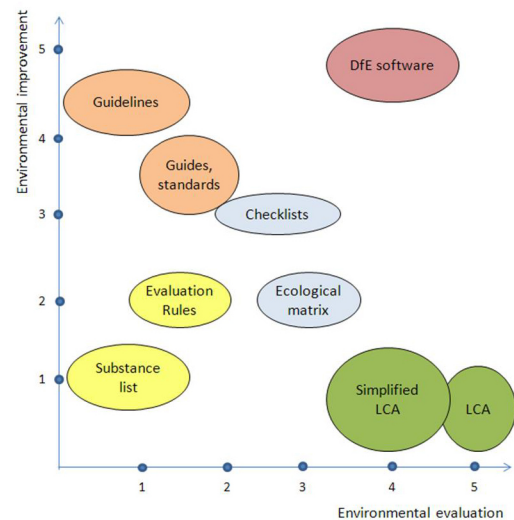


Figure 2. Ecodesign solutions ranking (adapted from [8])

These solutions will be described together with their advantages and drawbacks in the next paragraphs.

- **Substance list/Rules** are used to evaluate the impact of a product based on its composition. It can be used by companies but is especially enforced by regulations authorities which publish list of substances of interest. These regulations force companies to track or eliminate substances from their product. This type of solution is neither an evaluation nor an improvement tool and could not be used as is. Consequently, it will not be considered further in the context of this article.
- **Guidelines/standards** are a collection of general rules used to implement ecodesign within a company. These documents are useful as a reference to understand the strategy to adopt in order to implement ecodesign within a specific industry. However, they remain often too general to be applied specifically in a design context by engineers [9]. These documents are also not quantitative, meaning that it is not possible to compare the environmental impact of several design choices without coupling them with an evaluation tool.
- **Life cycle assessment (LCA)** is defined by ISO14040 standard as the “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (from raw material extraction to the end of life of products) [10]. According to Lewis *et al.*, LCA is one of the most reliable tools for evaluating the whole industrial production system [11] because of its scientific rigor [8]. However, LCA represents a very detailed product analysis and requires a lot of data which is not yet available at detail design stage, especially regarding aerospace manufacturing processes. This gap might prevent companies from applying full LCA as it could bring uncertainty to the results and ultimately lead to misleading

conclusions [12]. Moreover, it shall also be noticed that LCA does not include some environmental aspects that could be relevant from an ecodesign perspective such as regulations for hazardous materials or end-of-life challenges [13].

- To address the limits of LCA, the *simplified LCA* concept which restricts voluntarily the scope of the study to only focus on identified hot spots and consequently dramatically reduces the time spent on the study has been created. However, it still not overcomes data availability problems identified earlier. Consequently LCA, as is currently, could still hardly be integrated into detail design process.
- *Checklists* are a list of questions that allows product analysis from an environmental viewpoint. They do not allow an environmental evaluation in the strict sense, but have the advantage of easily and quickly ranking a product/process over another through strategic parameters which can influence its footprint. Checklists can be used upfront of design activities [14]. They are very useful in a context of environmental improvement because they put a focus on the hot spots and can be coupled with ecodesign strategies that could reduce the environmental footprint of the product.
- *Environmental matrices* are evaluation tools based on the identification of environmental aspects through all the life cycle phases (materials, manufacturing, operation, end-of-life and transport). They can be qualitative, semi-quantitative or quantitative. The main advantage of this methodology is that it represents a good trade-off between improvement potential and environmental evaluation relevancy. It allows identifying hot spots from a product without needing too many input data. This would make matrices a good tool to evaluate the environmental impact of a product at detail design stage. The most famous and used environmental matrix regarding manufactured goods is the Environmental Responsible Product (ERP) matrix [15]. This 5×5 matrix has been developed by Graedel [16] and has then been applied in numerous case studies including some in the aerospace industry [17, 18, 19]. ERP matrix evaluates semi-quantitatively the environmental impact of a product with five environmental stressors over five life cycle stages. An example of ERP is given on Figure 3 where cell indices are indicated. This methodology uses a ranking system from 0 (very high impact) to 4 (very low impact) for each environmental stressor at each life cycle phase. The cell score can be determined by answering a series of yes/no questions designed to address the life-cycle stage and stressor that characterizes it [20]. Finally, a global score can be obtained by summing all cells from the matrix. This methodology is very interesting as it allows comparing quickly and easily a range of products based on the same set of indicators and to identify hot spots in order to reduce the footprint of a given product. However, the assignation of the scores has been criticized for its subjectivity aspect by some authors [21]. ERP matrix also does not weight results, leading to provide the same importance over all entries. Consequently, this tool could not be used as is in the aerospace industry where more

than 90% of environmental impacts are concentrated on the operation phase [22].

Life cycle phases	Environmental stressors				
	Material choice	Energy use	Gaseous residues	Liquid residues	Solid residues
Pre-manufacturing	1,1	1,2	1,3	1,4	1,5
Manufacturing	2,1	2,2	2,3	2,4	2,5
Delivery	3,1	3,2	3,3	3,4	3,5
Use	4,1	4,2	4,3	4,4	4,5
End-of-Life	5,1	5,2	5,3	5,4	5,5

Figure 3. Example of ERP matrix. Values indicated in each cell are their indices and are for information only.

- Finally, full *DfE software* represent the best trade-off between environmental evaluation and improvement as can be seen on Figure 2, they integrate a full life cycle assessment tool coupled with ecodesign recommendations on how to implement solutions which could influence the environmental impact of the studied product. These tools are of very high quality. However, they are usually very difficult to use and time consuming. Nevertheless, they constitute a goal to reach in terms of analysis quality and optimization potential.

As a result, although a large number of methods and tools have been developed for implementing Design for Environment within a company, few methods can directly be used by engineers at detail design phase of an aircraft effectively and consistently. As a first step, environmental matrices, especially the ERP matrix, and checklists seem to be the most promising methodologies as they represent a good trade-off between evaluation relevancy and improvement potential (Figure 2) without being too complicated to integrate within a product development system.

As mentioned previously, a new methodology on how to take into account the environmental aspect at detail design phase of an aircraft for integration in an optimization framework will be developed in this article. Section 2 presents the framework in which our methodology will be integrated. It also develops the methodology which couples a checklist with an environmental matrix in order to easily quantify the environmental impact of materials/processes. Then, Section 3 shows an application of the approach to a series of tested processes in order to demonstrate the feasibility of the methodology.

2. METHODOLOGY

2.1. Presentation of the MDO Framework

Bombardier Aerospace has recently developed a tiered MDO framework for supporting the concept of the right level of fidelity at the right stage [23]. Levels 0 and 1 are associated with the conceptual phase of the aircraft development. They thus refer to CMDO (conceptual MDO) where several aircraft configurations are explored to find the best design space regions fulfilling the business case. Thereafter, level 2 named as PMDO (preliminary MDO) is intended to further refine the solutions highlighted by CMDO