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# Sustainability assessment of dismantling strategies for end-of-life aircraft recycling

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ABSTRACT

With the current increase of environmental concerns, conventional methods practiced at end-of-life would not be capable to sustain the growing amount of retired aircrafts waiting for final disposal in the scrap yards each year. Material recycling is known as an important environmentally friendly activity. The quality of recycled material in a recycling process is actively influenced by an appropriate disassembly/dismantling strategy. In recycling the carcass of the aircraft, it is suitable to separate and classify different aluminum grades into their main alloys family before sending them to recycling center (i.e. 2xxx and 7xxx). However, due to complexity in the aircraft structure, fully disassembly/dismantling or fully shredding the aircraft is not economically or environmentally viable, respectively. For this reason, this work discusses eight different disassembly/dismantling strategies that have been done on a real Bombardier Regional Jet aircraft. The study narrows the gap in sustainability evaluation of these strategies by using an efficient fuzzy assessment method. Ten different risk scenarios were considered to have a robust understanding about the sustainability performance of each strategy. The methodology used in this work allowed to select the best strategy in terms of sustainable disassembly/dismantling.



## 1. Introduction

According to Airbus's report (Airbus, 2008), "Process for Advanced Management of End-of-Life of Aircraft (PAMELA)", around 85% of the weight of a civil aircraft can be recovered (15% for reuse, and 70% through recycling). Recycling includes collecting and sorting recyclable materials that would otherwise be considered as waste and then processing them into raw materials for future aircrafts or other industrial applications. Excellent environmental benefits come out from recycling high-tech aerospace alloys rather than production from virgin materials (Asmatulu et al., 2013a).

Sustainability and sustainable development are more and more becoming the center of attention for different industries. Ideally, in sustainable development should be considered the entire supply chain including end-of-life (Jayal et al., 2010). Frosch and Gallopoulos (1989) pointed out: "Wastes (end-of-life materials) from one industrial process can serve as the raw materials for another, thereby reducing the impact of industry on the environment". Acting as supplier for bigger industries, aircraft dismantler/recycler businesses should focus on strategies that allow to ameliorate their current position in the market. One of the key factors is to practice sustainability and sustainable development in all the dismantling and recycling processes.

One of the major problems in recycling aircrafts is aluminum recycling. An interesting study performed in aircraft manufacturing facilities in Wichita, revealed that only 20% of the potential recyclable aluminum from 1765 aircrafts was actually recycled (Asmatulu et al., 2013b). Shredding has been extensively used as a pre-recycling method that allows transforming huge components of the aircraft into smaller and more practical dimensions. Fully shredding an aircraft as a whole piece, results in a mixture of different aluminum alloys with different grades and leads to a very low alloy quality. This low quality aluminum requires additional treatments to recuperate the mechanical properties that make it suitable for appropriate applications.

Although efforts have been directed towards improving the aluminum recycling methods (Gaustad et al., 2012; Grimes et al., 2008), the lower is the quality of the aluminum alloy retrieved, more additional treatments are required and more costs associated. In this situation, it is preferable to disassemble/dismantle the components with different grades of aluminum alloys into their main

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alloy families prior to shredding (Das and Kaufman, 2008; Mascle et al., 2015).

In our knowledge, little attention has been paid to implementation of dismantling and pre-sorting strategies that can ameliorate the quality of alloys prior to recycling. In this study, eight different disassembly/dismantling strategies before shredding were developed under the project "Process for advanced management and technologies of aircraft end-of-life" (CRIAQ-ENV412). These strategies were applied to a real Bombardier Regional Jet aircraft. The main focus of this paper is to shed the light on process of sustainable strategy selection in different risk scenarios. The three-bottom-line (TBL) concept (environmental, economic, and social sustainability) was taken into account.

Including this introduction, Section 2 presents the eight disassembly/dismantling strategies; in Section 3, hierarchical structure for the TBL is introduced; the application of a fuzzy assessment is presented in Section 4; evaluation of the strategies in different risk scenarios is given in Section 5; and finally, Section 6 presents the conclusion.

## 2. Disassembly/dismantling strategies

The main goal of testing different disassembly/dismantling strategies is to minimize the cost–benefit ratio and environmental impact of the recycling process. Cost is dependent on the time and number of employees required. Benefit can be translated as the market value of the retrieved material. A homogenous package composed of the same material is more valuable than scraps: mixture of different materials. It is worth mentioning that the relevance of costs and benefits may vary considering the local context (e.g. country, city, urban or rural environment). For instance, the labor cost in China is less than the one in North America. This fact might influence the selection of the final strategy depending on the local context.

Disassembly is the act of separation, and separation is acquired when the joints for the two components are clearly removed (Lambert and Gupta, 2004). A rigorous disassembly can be tedious and time-consuming, but is the best way to avoid cross contamination of different materials for recycling purposes. On the other hand, the action of cutting is to make an opening or incision in (something) with a sharp-edged tool or object. In terms of dismantling operations, cutting has been commonly used. However, cutting parts usually implicates that a certain portion of material *X* will be mixed with a higher concentrated material *Y*.

*Strategy A—Systematic disassembly:* The purpose of this strategy is to separate and sort all the components based on material composition. The attachments are also removed and sorted. The identification of the material is performed using Niton, portable X-Ray fluorescence analyzer. Typically, the removal of one aluminum rivet takes 15 to 20 s; while that of for titanium rivet is more than 2 min. Disassembling the top-skin of the Regional Jet left horizontal stabilizer takes an entire work day. Although *Systematic disassembly* is labor intensive, it is the best strategy in terms of segregation of different type of materials. In other words, this strategy is concentrated on quality rather than quantity.

*Strategy B—Shredding:* The aircraft is cut into small pieces for transportation to recycling center. Each piece is compound of different types of materials: aluminum, titanium, steel, plastics, composite, glasses, rubber, etc. Unlike *Strategy A*, *Shredding* is concentrated on quantity rather than quality.

*A* and *B* strategies are considered the extremes in cost–benefit ratio. *Strategy A* has the highest potential cost and highest quality of retrieved materials; on the contrary, *Strategy B* has the lowest for both. *A* and *B* are not fully desired to be practiced in industries because of the excessive costs and poor material quality associated to *A* and *B*, respectively. Intermediate strategies can be defined using the available mapping of the aircraft. The mapping contains information for material composition of each component. The following strategies are based on the use of this aircraft mapping.

*Strategy C—Smart shredding:* Instead to cut the carcass randomly in pieces, *Smart shredding* selects zones on the carcass based on the mapping. The selection takes regions with higher frequency in similar type of materials. This fact may result in more homogeneous pieces before shredding. However a very limited number of cuts are established in this strategy.

Additionally, it is remarkable to mention that when the selected piece is removed a mass balancing analysis is required to estimate the type of alloy that will be retrieved. This information helps stakeholders to save the intrinsic properties of the materials.

*Strategy D—Gross cutting:* This strategy is conceptually similar to *Strategy C*, but more cuttings are allowed. Consequently, powerful and moveable cutting tools are required. These tools are often bulky and fuel-based permitting to cut fast but noticeably imprecise.

*Strategy E—Semi-gross cutting:* Unlike *Strategy D* this strategy requires more precise cuts in order to increase the homogeneity of the packages. More precision demands for lighter and powerful cutting tools. Most of these tools are electrical.

*Strategy F—Detail cutting:* As the name suggests, this strategy implies a high amount of precise cuttings. It obliges to have more precise tools, which are usually smaller and handy pneumatic tools. Unlimited cuts are allowed which implies that this strategy be laborious and time-consuming.

*Strategy G—Smart disassembly:* The main concern about *Systematic disassembly* is the time and effort spent to remove the attachments. The question is: "Do we really need to remove all the attachment?" The goal of this strategy is to alleviate the excessive time needed to remove the attachments in *Strategy A* by NOT removing rivets that are shared between components with similar material composition. Though, the quality of recovered material is compromised due to inclusion of these attachments.

*Strategy H—Disassembly combined with cutting:* In this strategy, *Systematic disassembly* and *Detail cutting* are combined. First, a meticulous analysis of the whole carcass or the pieces to be recycled needs to be accomplished. The areas to be cut are the ones with higher density of the same or similar materials; on the contrary disassembly should be done in heterogeneous regions where each component has a different material.

## 3. Sustainability drivers

After group meeting with the partners and decision-makers in the project, it was decided to analyze the strategies with respect to TBL concept. This process of knowledge extraction from the experts was performed using pseudo Delphi[1] method. Having presented the problem and importance of sustainability as a key factor, decision-makers agreed that the TBL approach was suitable to solve the problem.

In the following part of the survey, experts were advised that one of the important steps to start the analysis is to determine the

[1] Delphi is a structured communication technique, originally developed as a systematic, interactive forecasting method which relies on a panel of experts. The experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. Generally, the range of answers decreases and the group converges towards the "correct" answer. The process is stopped after a pre-defined stop criterion (e.g. number of rounds, achievement of consensus, and stability of results) and the mean scores of the final rounds determine the results.

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