KEYWORDS ▪ Assembly ▪ eco-design ▪ recycling ▪ aeronautical projects ▪ sustainability

AIRCRAFT ECO-ASSEMBLY: A STRATEGY TO REDUCE THE ECOLOGICAL FOOTPRINT OF AEROSPACE INDUSTRY

ABSTRACT

The aerospace industry is a vector and a destructive agent for the environment. It is observed several pollutants and harmful wastes in all aeronautical activities. Given the negative impacts of the aerospace industry on the environment, large organizations such as Airbus, Boeing, Bombadier and Embraer have taken awareness of the urgency to inhibit environmental footprint. It has become imperative to design flying machines that could be less harmful for the environment. Therefore, aerospace industry has undertaken initiatives to limit its environmental footprint for two main phases of the aircraft lifecycle, named utilisation and final disposal. For utilisation, eco-design was used to reduce energy dependency and reduce pollution rate. For final disposal, eco-design enables aircraft recycling or final disposal under legal and industry norms. However, our literature review highlights the gap for projects to reduce environmental footprint during aircraft assembly. This paper identifies the main sources of pollution during the aircraft assembly phase and evaluates the possible strategies or initiatives to be undertaken to reduce waste quantity and to ensure their management. These strategies are named in this paper as eco-assembly.

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INTRODUCTION

The aerospace industry maintains a constant step for expansion since the onset of the first aircraft. It has experienced several transformations to better respond to the market requirements and environmental changes. It has passed from mass transportation in the 80s and 90s to developing more environmentally responsible products. This last transition corresponds to their environmental footprint. The aerospace industry, having activities with other sectors, is a vector and a destructive agent for the environment. It is observed several pollutants and harmful wastes in all aeronautical activities. Furthermore in the coming years, more than 6000 aircraft will be recycled: a quarter of the area of Paris. Regarding CO2 emissions, an aircraft emerged between 134 and 148 grams of CO2 per passenger per kilometer against 2.6 grams generated by a train *(Encyclo-ecologist, 2012)*. We can also rely its environmental impacts to the great outdoors space that it requires not only for its deployment, but also for the end of life of aircrafts For example, 1.7 million metric tons of aerospace WEEE *(Waste Electrical and Electronic Equipment)* is collected each year in France *(Mugnier, 2008)*.

Therefore, how can aerospace industry define an optimal strategy to inhibit the proliferation of wastes hile maintaining its growth and its usefulness? This research focuses on an essential phase of the aircraft life cycle namely the assembly. This paper has three objectives: *(i)* identify the main sources of pollution during the aircraft assembly phase, *(ii)* evaluate the possible strategies or initiatives to be undertaken to reduce waste quantity and to ensure their management and, *(iii)* assess the ability of eco-assembly to reduce the environmental impacts during the aircraft-assembly phase.

This paper is structured in five sections. The first one discusses the environmental context of the aerospace industry. The second part presents the literature review focusing on the most discussed concepts to manage environmental issues: eco-design. The third and fourth sections illustrate respectively the methodology and results. Finally, the last section presents the conclusions of this research project.

1. Aerospace industry and its environmental footprint

Impacts

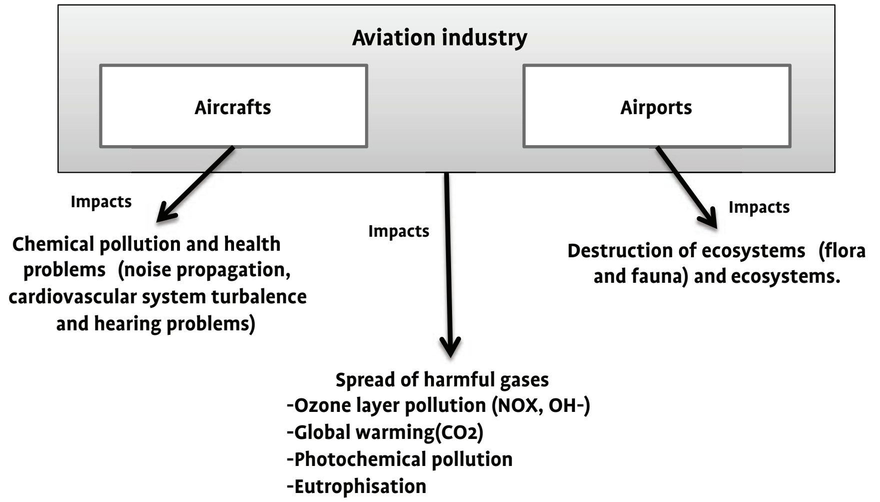
ADVOCNAR *(2014)* highlights global warming, chemical pollution and healthcare problems as the main polluting effects of aircrafts on the environment. In terms of global warming, experimental studies show that aircrafts spread 2% of the total worldwide CO2 *(ATAG, 2012)*. This polluting effect increases when studies integrate NOx and analyses the formation of cirrus clouds. ADVOCNAR work *(2014)* stated "aerospace industry contributes from 4 to 8% to global warming."

In the case of chemical pollution and healthcare problems, Lamure and Vallet's work *(1990)* provides a framework to identify aircraft effects on environment *(see* **Figure 1***)*. For them, the first effect is the aircraft noise. It could produce healthcare problems *(such as sleep disturbance, cardiovascular system turbulence and hearing disorders)* and discomfort for humans and their habitat. Furthermore, spread gasses pollute local, regional and global environments. At local level, the General Directorate of Civil Aviation Airport *(2003, p. 9)* showed that "gasses could be found on the vicinity of emission sources such as industrial furnaces combustion, traffic routes, domestic heating, waste incineration and airports". It added that these gasses participate in the urban pollution background. Lamure and Vallet's work also highlights the regional pollution that could reach spaces that are several miles from the pollution source. They found gasses in various forms such as acidification, photochemical pollution and eutrophication. This pollution contributes to the destruction of the ozone layer by emission of nitrogen oxides and OH- ions. Finally, the destruction of ecosystems is also cited in this work. Directorate General of Civil Aviation Airport *(2003, p. 25)* stated "the Airbus A320 crash from Surabaya *(Indonesia)* to Singapore December 28, 2014 reveals that aviation contaminant *(...)* could produce ecosystem imbalance such as food chain breaking, habitat disappearance and outbreak of a competing species. They could also disturb ecosystem behaviour: for instance, pollutants could become nutrients for some species".

The green aircraft

Given the negative impacts of the aerospace industry on the environment, large organizations such as Airbus, Boeing, Bombadier and Embraer have taken awareness of the urgency to inhibit environmental footprint. It has become imperative to design flying machines that could be less harmful for the environment. Actual efforts are concentrating to create the first green aircraft. The idea of developing a "green flight" was born in October 2008 at NASA. NASA's goal is to reduce aircraft fuel consumption, emissions and noise simultaneously, which is a much more difficult challenge than working to reduce them individually. ONERA *(French aerospace lab)* also

FIGURE 1. *Aerospace industry effects on environment*



developed a prototype for the aircraft of the future. For them, a green aircraft will be fully automated and powered by non-fossil fuels. "It will use electric, solar, or perhaps nuclear energy because the aircraft of the future will fly an air space where management traffic will be fully automated "*(AAO, 2013, p 9)*.

Werner and co-authors *(2007)* estimate that new generations of aircraft will improve energy efficiency, reduce fuel consumption, and will be less polluting. To do this, Dassault *(2011)* proposes to lighten aircraft structure by using composites. In addition, Dassault *(2011)* proposes to improve electronic equipment and energy systems while minimizing streaks. These studies also include the design of highly integrated systems; which will reduce noise and dilute engine sounds. Finally, Dassault *(2011)* suggests adopting eco-design for materials and recycling for aircraft systems and components.

The green aircraft should be closer as possible to an environmentally friendly product. The idea is to use non-toxic materials for all phases of its life cycle. Mugnier *(2008)* highlights eco-design as the mean to achieve this deal:

- First, incremental eco-design aims to favour the development of projects facilitating progressive environmental improvement for existing products based on the existing technologies. Eco-design could improve material efficiency and product safety.
- Second, eco-design could also introduce new concepts or technologies to lower environmental impact for consumers.

Main environmental projects

Aerospace associations, manufacturers, suppliers and service providers have undertaken various projects to manage their environmental footprint:

- The International Civil Aviation Organization (ICAO) has developed a new computer training program to guide, plan, and provide solutions for managing risks related to wastes generated by the aerospace industry. This project contributes to the development of the Continuous Monitoring Method (CCM) for the Universal Program for Security Audit and Supervision.
- The world's two largest commercial airframe manufacturers, Airbus and Boeing, are at forefront of drive to develop best practices for recycling airframes. Whit PAMELA process (Process for Advanced Management of End-of-Life Aircraft Program), Airbus has coordinated and built Tarmac Aerosave organization to recycle, reuse or recover components of an aircraft (Gifas, 2011). This project demonstrated that 80 to 85 % (by weight of an A300) could be sold to licensed recovery channels. Furthermore, Tarmac Aerosave demonstrated that 70 to 75 % (by weight) of parts and equipment could be re-used or secondary raw materials recycled back into the aerospace supply chain (e.g. Aluminum). In Canada, Aero Montreal and Bombardier work together to lead two recycling projects.
- IFPEN (2014) describes four projects that have been implemented to reduce the environmental footprint of the aerospace industry. The TIMECOP-AE Project (Toward Innovative Methods for Combustion Prediction in Aero-Engines) (2006, 2010) aims to develop methods that contribute to the creation of combustion mechanisms for future aircraft engines. These motors should respect emission quality standards, and their hydrocarbon consumption remains low. Then, ALPHA-BIRD project (Alternative Fuels and Biofuels for Aircraft Development) (2008, 2012) and SWAFEA (Sustainable Way for Alternative Fuels and Energy for Aviation) (2009, 2011) are dedicated to the selection and the evaluation of the most promising alternative fuels, at a middle, short and long term, respecting sustainability. And finally, the project KIAI (Knowledge for Ignition, Acoustics and Instabilities) (2009, 2013) aims to provide reliable methodologies to predict the stability of industrial low NOx combustors and their ignition process.

2. Literature review

Given the above analysis *(section 1)*, it seems that eco-design is adopted by the aerospace industry as a way to develop a faster plane, cheaper and certainly less polluting. How has eco-design been integrated into the aerospace industry?

Eco-design

An eco-friendly product is "any product that causes less negative impact on the environment throughout its life cycle *(from raw materials extraction to the end of product life)* and maintains its performance during all its life" *(Jouanne, 2010, p.7)*. From this definition, an aerospace eco-product can be defined as any product or service that generates minimum adverse effects on the environment and ecosystem during each stage of its cycle: from its design to the end of their utilisation. Eco-design is known by numerous other names such as green design, design for environment, sustainable design, environmentally conscious design, life cycle design, life cycle engineering or clean design.

Eco-design greatly contributes to "the systematic integration of environmental considerations into product design and its realization process" taking into account the entire product life cycle *(Knight and Jenkins, 2009; Deniaud et al ., 2012)*. Blum *(2014)* and Deniaud et al., 2012 added that "eco-design is part of eco-innovation enabling products being more environmental oriented towards technological innovations".

Cost savings and increased sales are frequently claimed to be business benefits gained through eco-design *(Mathieux, 2002)*. This can include cost savings linked to improved material use or manufacturing efficiency on account of simplified products. In addition, improving product quality or reducing environmental impacts can achieve competitive advantage. Adopting eco-design may also increase brand strength and client perceptions. However, not all product improvements are attributable to economic drivers. In some cases, a moral decision to design better products is the real motivator.

Jouanne *(2006)* showed eco-design issues, highlighting the key role of existing regulations:

- The Europe RoHS regulation (2002/95/EC) aims to limit the use of six hazardous substances, which are: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE). This regulation looks forward to limiting these substances because of their negative impact on public health, environment, economy and sustainability.
- The Electrical Equipment and Electronic Waste regulation (WEEE) classifies wastes into three categories. The fist classification is white waste, related to garbage from household appliances. For instance, aerospace industry generates white waste on airports. Household equipment is used for airport restoration services for employees and customers. The second classification is gray wastes from computer and telephone residues. Finally, the last class is brown wastes generated by audio-visual equipment. These three classes of waste should be collected, triggered and eliminated following strict procedures.
- The Registration, Evaluation, and Authorisation of Chemical plan (REACH) has been undertaken on June 2007. This regulation looks for improving previous regulatory framework of the European Union for chemical substances. It aims to protect human health and environment against the adverse effects of chemicals.

For Jouanne *(2006)*, eco-design adoption and diffusion depend on the evolution of the above regulation. For instance, the Integrated Product Policy *(IPP)* defines environmental strategies for all products and includes the participation of all stakeholders involved into their lifecycle. IPP focuses on the following steps:

- The "polluter pays principle" that integrates the environmental costs on the product price,
- Consumer preference: user education by publishing information (via the media, posters, etc ...)
- Green design products

Industry organizations also encourage eco-design. For instance, ACARE *(Advisory Council for Aeronautics Research in Europe)* offers a public and private partnership to obtain the necessary funding for stimulating eco-design as a waste reduction strategy into the aerospace industry.

Methods and tools to apply eco-design

Eco-design can be applied by different methods into product development. Some methods are more appropriate for specific products and others should be considered for developing more complex artefacts. In the case of the aerospace industry, all eco-design methods have been used because of the complexity represented by the aircraft systems and sub-systems. The eco-design methods for product analysis and/or development most used in the aerospace industry are:

"DESIGN FOR X" *(DFx)* method encourages holistic product development, considering all aspects of the product in design decisions. X may correspond to one of many quality criteria, from more general, such as reliability, appropriateness for assembly, robustness, and maintainability, to more specific, like environmental impact, ergonomic and aesthetic value, etc. Effective DFx practice leads to low manufacturing costs without sacrificing product quality. DFx is one of the most integrative practices involved in product development. All members of the development team as well as outside experts need to contribute to identify specific design issues and propose solutions. Several factors have motivated DFx integration into the design of products, such as organizational competitiveness and consumers' pressures *(Canada Industry, 2010)*. The Canadian Industry report *(2010)* states that "Design for X" permits to accomplish product requirements *(such as assembly, quality, disassembly, manufacturing, safety and environmental impact)* while reducing costs.

According to Wang and Zhao's vision *(2008)*, **systemic design** is based on the "systemic approaches to change product design in function of customer's requests based on the fundamental architecture of the product and the stakeholders mobilization". Common systemic design methods include brainstorming, affinity diagrams, rich pictures, systems maps and prototyping. As tools, methods provide a set of constraints on task performance, which yields improved control both in terms of outcome and structure of performance of the task *(Habdi, 2014)*. Systemic design methods amplify natural human capacities to facilitate collaborative reasoning, visualizing, and making. When systemic design projects involve co-creation with stakeholders who may be unacquainted with the principles of systems thinking or design, methods are especially useful to encourage patterns of engaging with collaborative work that may be unfamiliar to many participants. However, Hadbi *(2014)* points out some limitations of this approach. First, he notes the system complexity and the difficulty to standardize their various components. Finally, Habdi described as limit the restrictions that may be derived from information asymmetry: incomplete or unreliable information.

Tukker and Jansen *(2006)* describe **product-service system PSS** as a competitive system of products, services, supporting networks and infrastructure. The system includes product maintenance, parts recycling and eventual product replacement, which satisfy customer needs competitively and with lower environmental impact over the life cycle. The key idea behind product service systems is that consumers do not specifically demand products, per se, but rather are seeking the utility these products and services provide. By using a service to meet some needs rather than a physical object, more needs can be met with lower material and energy requirements *(Ronald et al., 2007)*. In the PSS method, the relationship between producer and stakeholder is recognised with a wide scope. PSS encompasses the whole product lifecycle and extends to community and the environment: earth's lithosphere, earth's biosphere and solar energy. Then, it can contribute to the changes towards optimisation of the comprehensive system. In the traditional business model, producer has paid every effort to sell out goods *(Alix et al., 2011)*. Without material circulation, the model forces raw material suppliers to exploit natural resources from the earth's lithosphere and sell it to producer. Used products are left in the environment and earth's resources are kept being reduced. Producer can be excluded from community as the relationship between producer and community is only on monetary terms. On the other hand, producer of PSS business model provide services to customer, which makes materials of the product go back to producer or supplier and reduces the amount of waste and usage of virgin materials *(Balgin and Malleret, 2005)*. Furthermore, by increasing services via human resources, the producer can be included in the community, and can build an economy of scope rather than economy of scale.

LIFE CYCLE ANALYSIS LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by compiling an inventory of relevant energy and material inputs and environmental releases. In addition, LCA permits to evaluate the potential environmental impacts associated with identified inputs and releases and interpreting the results to help decision-makers make a more informed decision *(ISO 14040, 1997)*. By examining the product or service over its entire lifecycle, informed decisions can be made to avoid transferring pollution from one life stage to another or from one media *(air/water/soil)* to another. Although carbon emissions and carbon foot printing are very important aspects of life cycle studies, carbon is just one of many elements evaluated within an LCA *(SETAC, 1996)*. LCA provides many benefits, however inventories of the inputs and outputs are collected based on where they occur, and then are translated into environmental impacts on a global or regional scale. The results from an LCA identify potential impacts on the environment and are not a calculation of actual impacts. Therefore, LCA cannot replace local studies such as ecosystem-based studies of forest dynamics and biodiversity *(Graedel, 1998)*. In addition, its implementation remains difficult, or at least not very effective because of problems relating to the acquisition of data, time and cost.

Getting profits from eco-design

Literature reviews highlights eco-design as a key component for integrating environmental stakes in product and service development. Berneman and co-authors agree with this concept but they also describe eco-design as an approach enabling companies, customers and partners' profitability *(Berneman et al., 2009)*.

Berneman and co-authors' work shows how companies could get a more important income from introducing eco-design into products and services development. In fact, eco-design generates at least two different economic benefits:

- Increasing revenues by better accomplishing consumer demands. Customers become a more informed and environmental responsible. Then, they could ask for eco-designed products.
- Reducing manufacturing and recycling costs. Mugnier (2008) classified this benefit in eight potential areas: easy recycling, recycled materials, management of risks related to materials and substances, renewed materials, optimized materials, optimized logistics, renewable energy and sustainability strategy.

3. Methodology

Research context

Eco-design in aerospace industry triggers environmental considerations into aircraft development beyond the traditional perception that generally focused on political, economic, social, technological, and legal issues. Traditional aircraft development is based on product lifecycle analysis where each product could be split up from raw materials extraction, through designing, manufacturing, distributing, utilisation, recycling, and final disposal *(Gendron and Revéret 2010)*.

Based on the aircraft lifecycle analysis, we identified several actions undertaken by the aerospace industry to reduce its environmental footprint in two main phases of the aircraft lifecycle, named utilisation and final disposal. For utilisation, eco-design was used to reduce energy dependency and reduce pollution rate. For final disposal, eco-design enables aircraft recycling or final disposal under legal and industry norms. However, our literature review highlights the gap for projects to reduce environmental footprint during aircraft assembly. Several questions arise from this remark: Does aircraft assembly have a negative impact on environment? Which are the main wastes identified during assembly phase? Are there initiatives to reduce waste sources or to manage wastes? Could eco-design bring benefits to reduce the ecological footprint during assembly? Could eco-design decrease waste sources and help to better manage them? Which additional strategies could be applied? How could industry name these strategies?

Methodological strategy

To answer the above question, an exploratory study was executed. An exploratory study permits to find essential and strategic benchmarks for innovation. Furthermore, it allows integrating an ethnological point of view to highlight some cultural features. This methodological strategy fits with this research project because of the following reasons: topic novelty, a reduced sample *(organizations executing aircraft assembly)*, knowledge optimization and, research benchmarks.

A literature review and a content analyze were performed. Two main sources of documentation were used: scientific papers and industrial papers published on the Internet. Scientific documentation has been a significant and unavoidable intake. It comes from scientifically papers and journals specialized on eco-design and aerospace waste management. Empirical evidence was validated by secondary research methods, such as face-to-face interviews with experts on aerospace project management, eco-design and assembly.

Unit of analysis: assembly phase

Product lifecycle is a process that takes its essence through the acquisition of the raw material, continues with the processing, transportation, logistics, manufacturing, maintenance and, product end of life. In the case of aircraft *(see figure 2)*, several actors support its product life: manufacturers, customers, systems and services providers. They could undertake eco-design and other strategies to mastery each aircraft lifecycle stage and decrease its environmental footprint.

Figure 2 highlights in red our unit of analysis: assembly processes. Alder *(2007)* proposes a model to study assembly processes and identify how manufacturers can manage its activities to respect the environment. This model split assembly stage in 10 main industrial processes. These processes are listed in **Figure 3**.

4. Results and discussion

Based on the analysis of assembly processes defined by Ader *(2007)*, the literature review and the interviews with assembly specialists, we identified different sources and types of waste generating during aircraft assembly *(see* **Table 1***)*. Some

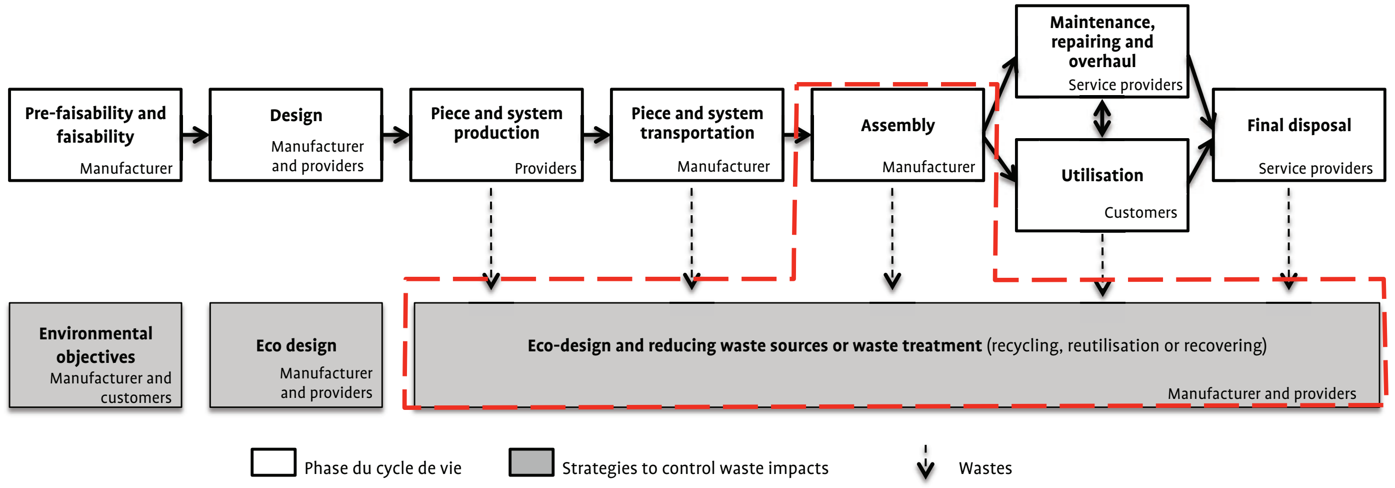


FIGURE 2. *Aircraft life cycle and its relative environmental strategies*

are chemicals such as oils, iso-cyanate or carcinogens. Some others are solid products such as cardboard, paper or metal.

To reduce the environmental footprint from assembly, it is necessary to undertake several strategies. While eco-design allows attacking waste problem from its source, recycling and safe disposal ensure responsible treatment of wastes. These three strategies are related to the eco-assembly concept.

Eco-design

Eco-design aims to redefine the design of systems, sub-systems and components in order to reduce waste sources or change waste characteristics, so that they have a fewer impact on the environment. Most of wastes produced during assembly processes could be reduced if eco-design is adopted for assembly. If system and part providers work in synergy with manufacturers, they could reduce wastes by better selecting raw materials and defining assembly processes that produce zero-wastes or a reduced quantity. Eco-design can also bring benefits for recycling. Designers must incorporate into their conception environmental variables such as guidance for wastes recycling and information for disassembly. For instance, they should design their products so that wastes should be easier to collect, sort and manipulate.

Experts participating in this research propose the following strategies to reduce wastes during assembly through eco-design:

- Designing aircraft systems and parts that should be less harmful and polluting. For instance, a participant proposed to change assembly and fusions mechanisms using less polluting materials that could have adverse consequences on the environment. The aircraft wheels are quite illustrative. Tubed tires could be replaced by tubeless tires. An assembly specialist noted “Cirrus 2014 products include a complete set of wheels and braking systems enabling a weight reduction, increasing performance and dosage as well as enabling a major level of security.”
- Chemical compounds mixed at a high temperature for painting, manufacturing, and pieces assembly should be designed. This treatment enables an easy and safe recovery and reutilization of wastes.
- Eco-design strategies during tests should also provide opportunities to reduce noise pollution, air pollution and gas proliferation. For instance, NASA proposed in his Horizon 2025 strategy to design and produce a “green aircraft” respecting low-emission engines, economic constraints and less invasive test procedures.
- Improving communication with business partners, but also among business units of a same organization could promote eco-design. If manufacturers work in synergy with suppliers, wastes sources and quantity could deeply decrease. For instance, Berneman and co-authors (2009) propose to organize information and knowledge transfer activities, provide international monitoring, conduct research and publish information about best practices to promote environmental practices in the aerospace industry.

Recycling

An important quantity of wastes identified during the assembly process can be recycled or reused, such as paper, cardboard, packaging, carpet scraps, son or tissues, electrical and electro technical installations and metals. Recycling wastes generated during the general assembly and commercial completion could serve as secondary raw materials or be reused in other sectors. Manufacturers can set up three recycling strategies:

- Closed-loop recycling: wastes are reconstituted to its initial composition for being used as raw material for the same process or product
- Open loop recycling: wastes are reconstituted to its initial composition for being used as raw material for a different process or product
- Reutilization: wastes are reused for a new goal. In this case, wastes don’t go through a reconstitution process.

Given aerospace industry quality standards and regulation, recycled materials must meet the same characteristics as virgin materials. To

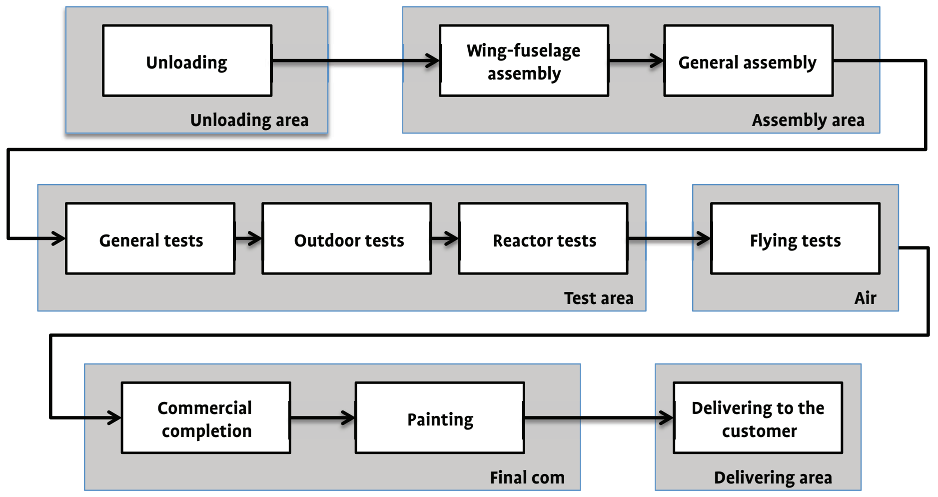


FIGURE 3. *Assembly processes from Alder model (2007).*

Assembly processes	Description	Wastes
Unloading	Aircraft components are discharged into an unloading area and transported to assembly area. Technicians unpack components from boxes or from plastic protective elements.	Packaging and secondary packaging Plastics Paper cartons
Wing-fuselage assembly	Central portion wings are positioned and fixed. The use of ferrous, non-ferrous and precious metals could generate wastes during assembly and alloy. Waste oil from the lubrication works could be quite harmful and polluting.	Ferrous, non-ferrous and precious metals Wasted oil Noise Electrical and electro technical installations
General assembly	Aircraft assembly gathers homogeneous and/or heterogeneous materials into the aircraft structure. To achieve this, assembly line must use techniques and specific and adapted methods, such as brewing, bolting, gluing, riveting, welding and face.	White Trash: appliances Gray waste: computer, and phone Brown waste: audio visual
General tests	These tests are executed to assess product quality: the good aircraft operation. They entail moving parts - output and landing gear input - avionics – sealing, electricity and water tanks - and transfer to the outside testing stations.	Gas proliferation Hydrocarbon proliferation Dust proliferation Destruction of large areas for testing Noise
Outdoor tests	Their goal is to assess the quality of the aircraft exterior parts. They include cabin pressurization tests **(containing air into normal pressure in the aircraft cabin space)**, gauges calibration **(measurements verification using evaluators devices)** and radio-navigation system tests **(correct communication between the outside and inside of the aircraft)**.	Gas proliferation Hydrocarbon proliferation Dust proliferation Destruction of large areas for testing Noise Used tires
Reactor tests	These tests start with reactor washing at high pressure and go with an audible alarm at high intensity, generating large vibrations. The goal of this last step is to clean the impurities found on the surfaces and on the engine. It follows tests for motor under maximum usage constraints. Technicians evaluate outbreaks, pressures, temperatures, and vibration.	Gas proliferation Hydrocarbons proliferation Noise
Flying tests	These tests are highly correlated with outdoor tests. The aircraft are equipped with a system of antennas allowing instant communication with the ground: telemetry. Flying tests assess manoeuvres, integrated systems and aircraft behaviour. There are two types of flight tests: flights development **(evaluate new aircraft models and authenticate them)** and critical flight **(air tests in difficult areas or cutting the reactor during full ascension)**.	Gas proliferation Hydrocarbon proliferation Dust proliferation Destruction of large areas for testing Noise
Commercial completion	Manufacturer installs furniture selected by the customer. Commercial completion includes: carpets, which are a fabric chain of velvety wool yarn, metal furniture and video systems **(televisions and computers devices)**	Carpet scraps, yarn or tissues Scrap metal Waste from televisions or computer equipment amortization
Painting	Penultimate stage of the assembly. Painting an aircraft to its colors is a mandatory passage. But before painting, aircraft surface should be prepared. To do this, it is necessary to strip the surface with specific chemicals and sand with hard sandpaper. Sometimes, technicians use chemicals to remove previous layer.	Substances classified as CMR (Carcinogenic, Mutagenic or toxic for Reproduction) Chromate (carcinogen category 2) Iso-cyanate (toxic for reproduction category 3) Paper or paperboard
Delivering to customers	Final stage of the process where customer receives the assembled aircraft.	Gas proliferation Hydrocarbon proliferation Dust proliferation

TABLE 1. *Assembly processes and their related wastes*

accomplish this, recycle process should be improved such as waste sorting and decontamination. Regulation demands for identifying contaminants and eliminating them during collection activities. However, it's complex to respect this requirement since decontamination machines could not be easily integrated into the collection process.

Furthermore, it is noted that some wastes could be difficult to be collected, sorted and decontaminated. In some cases, wastes are contaminated with other substances or chemicals, limiting their reuse. Even more, there is a feeling in the market that recycled products are unsafe or defective even if they have followed decontamination and reconstitution processes.

Safe final disposal

There is an important amount of wastes that unfortunately couldn't be reduced by eco-design or treated by recycling such as chemicals or radioactive wastes. To reduce their ecological footprint, the industry may use safe disposal procedures than enables the total destruction of pollutants.

There are several techniques that should be developing to establish final disposal:

- Sorting: it is a technique for separating wastes by homogeneous lots.
- Burial: this technique involves buried wastes in huge and deep graves allowing their transformation in biogas. Biogas is collected by a system of pipelines routing it to a facility that used it for producing electricity or heating. For example, in France, the Lorraine region city buried radioactive wastes in a 500-meters-deep grave to produce electricity.
- Incinerating: this technique enables to destroy polluted wastes by burning them at medium and high temperature temperatures into cement oven. This technique generates less air pollution than burning wastes at lower temperatures.

5. Conclusions

The empirical evidence obtained from this exploratory study highlights waste types from the aircraft assembly process *(proliferation of oil and gas, noise, destruction of large areas for testing, etc.)*. To minimize the influence of such wastes, organizations have focused on undertaking environmental responsible strategies *(eco-design, recycling and safe final disposal)*, called in this paper as eco-assembly. In this context, eco-assembly can reduce the negative impact on the environment from the extraction of raw materials to its re-use; while maintaining aircraft quality, functionality and performance. Eco-assembly is a preventive and curative strategy. Bombardier, for instance, has implemented a method "Plan-Act-Check-Making" *(PACM)* to decrease its environmental footprint during the aircraft assembly, but also to improve quality systems and processes. Experts describe this initiative as an innovative practice in this area.

Despite eco-design results to reduce the ecological footprint during assembly, it cannot completely reduce the amount of wastes. Recycling presents itself as the alternative strategy to transform waste in secondary raw materials for other activities either for the aerospace industry or for other sectors. For non-recycled wastes, there is a third strategy that enables final disposal. This strategy is based on sorting, landfill, biogas and incineration processes.

Operating in a highly competitive environment, aircraft companies could use eco-assembly strategies to reduce wastes related to its activities, but also to have differentiated and profitable deals. However, quality standard, regulations and collaboration should be developed in order to help aerospace industry to undertaken eco-assembly strategies.

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