AIRCRAFT METALS RECYCLING: PROCESS, CHALLENGES AND OPPORTUNITIES

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ABSTRACT
Until recently, end-of-life aircraft usually ended up in desert-based boneyards around the globe. However, the situation is slowly but surely changing as an increasing number of companies are becoming active in aircraft dismantling and recycling. The increase of activity is driven by the growing number of end-of-life aircraft as well as stricter environmental regulations. The materials recovery process is not, however, without pitfalls: manual materials separation maximizes the quality of the recovered materials while mechanical scrapping is far less costly. The mediocre quality of recovered metals often results in their downcycling. In addition, hazardous materials must be dealt with and fluctuating metal prices make it difficult to foresee and sustain the profitability of the activity. On the other hand, the recycling field also seems to hold a promising future: the number of retired aircraft is increasing and environmental awareness is on the rise. End-of-life aircraft constitute one of the currently underexploited ‘urban mines’ worthy of taking a closer look.

INTRODUCTION
Today, approximately 400 commercial aircraft are reaching the end of their life cycles each year and the number of retired aircraft is expected to reach 12,000–14,000 over the next 20 years. This would create up to 700 end-of-life aircraft per year. Recycling of end-of-life aircraft is nonetheless an activity that is only getting started on a large scale. It is difficult to find exact figures on the topic as there are no official centralized statistics; however, the Aircraft Fleet Recycling Association (AFRA), an industry association for aircraft recycling, estimates that its members have recycled thousands of aircraft, both military and commercial, since the creation of AFRA in 2006 [1].

In the future, there will be more and more need for aircraft recycling as the number of flying commercial aircraft and, in consequence, end-of-life aircraft is increasing. In addition, the average age of retired aircraft is decreasing as old aircraft are replaced with new more fuel-efficient models. Moreover, environmental consciousness, which is already fairly well developed in the Western world, is also on the rise in emerging countries such as China. In Europe, the spectre of future legislation on aircraft recycling could also be a partial motivator for recycling efforts.

Firms such as Airbus and Boeing have started to pay increasing attention to aircraft end of life and are developing their materials recycling and recovery processes. This has led to projects such as PAMELA-LIFE (Airbus) and the founding of AFRA (Boeing). The increasing attention to aircraft end of life has been encouraged by diverse factors from life cycle thinking and product stewardship ideas to image loss resulting from the storage of deteriorating aircraft and to parking costs [2].

One of the companies active in aircraft recycling is Bartin Recycling Group, a subsidiary of VEOLIA PROPRETE. A Clean Sky project named AIMERE (AIRCraft METals REcyling) is currently underway to analyse Bartin’s materials extraction process in order to propose process improvements. Another major goal of the AIMERE project is to find recommendations for Design for Recycling in order to facilitate the recycling process in the future. ENVISA, an environmental research and consulting company, is leading the project while Bartin focuses on its technical implementation. The focus of the AIMERE project and therefore of this report is on metals; other materials, such as composites and plastics, are given less attention.

AIRCRAFT LIFE CYCLE
The aircraft life cycle can be divided in 6 stages: design, manufacturing, operation, maintenance, parking/storage and end of life (EOL). In most cases, the end-of-life stage has been neglected; however, due to the increasing number of retired aircraft, there is a need to improve aircraft design in order to optimize end of life. A common practice at the end of life of aircraft has been the storage in airplane graveyards; this storage generally takes place in desert areas where there is enough space and where the climate conditions are favourable for aircraft conservation. During the outdoor storage, the condition of the aircraft begins to deteriorate and they can turn into environmental eyesores. On average, aircraft remain parked for two years after their last flight before dismantling [3]. It is not clear how many
Aircraft are currently dismantled and recycled annually and how many are merely parked on tarmacs and boneyards around the world. Some experts estimate that the number of currently parked aircraft is over 2,000 [4].

A somewhat idealized and simplified representation of the aircraft life cycle—from design to manufacturing, use, end of life and materials reuse—can be seen in Figure 1. In reality, not all recovered materials are recycled: some end up in incinerators for energy recovery whereas others are disposed of in landfills or in other specialized storage and treatment facilities. Even when recycling takes place, the secondary materials are usually employed in other than aeronautical applications.

**Materials Recovery Process**

Currently, the aircraft recovery process consists of ten main steps:

1. decontamination,
2. extraction of parts (under EASA PART 145),
3. transfer of the aircraft to the dismantling platform,
4. removal of landing gears (Figure 2),
5. preparation of the materials extraction phase,
6. interior stripping (Figure 3 and Figure 4),
7. customer cuts,
8. extraction of specific materials,
9. scrapping (Figure 5) and
10. shredding and sorting of the extracted materials.

Of course, this schema only applies to activities taking place on a fixed dismantling platform, whereas some companies also have mobile dismantling units for in-situ operations. In the aircraft preparation phase, spectroscopic analyses can be conducted in order to determine the locations of different valuable metals.

The dismantling starts with the stripping of interiors, in the cockpit (e.g. panels and avionics extraction) as well as in the cabin (e.g. removal of floor, seats and luggage racks). After this, a cutting phase takes place followed by hydraulic demolition. In the cutting phase, specific parts or sections (doors, windows, cockpit, etc.) of the aircraft can be extracted for various non-aeronautical uses and certain valuable metal parts (such as titanium beams) can be recovered. The plastic, composite and other wastes separated during interior stripping can be disposed of as non-dangerous waste. After the aircraft is scrapped, the recovered metals go to a shredder; after the shredding, they are separated using different sorting technologies such as density

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**On Aircraft End-of-Life Terminology**

The terminology of aircraft end of life includes various more or less well-defined expressions such as decommissioning, dismantling, demolition, disassembly, part-out, scrapping, retirement and recycling. Retirement corresponds to the removal from service; it can be either temporary or permanent. In the case of temporary retirement, the aircraft is parked and stored. Decommissioning represents the removal from service. Taken as a technical term, decommissioning can be thought to represent the servicing and decontamination phases of aircraft end of life. Disassembly comprises all the activities required to remove valuable components from an aircraft; these parts can be later recertified and sold while unserviceable parts are to be destroyed. The dismantling phase takes place after disassembly: it comprises the activities required to recover materials from aircraft and reduce it to scrap. Recycling is, generally speaking, the process of making materials available for reuse in order to create value. Technically speaking, recycling refers to the reprocessing of recovered materials so that they can be used to manufacture new products. However, aircraft recycling can also be thought to refer to the entire disassembly, dismantling and materials recovery process. In this article, the term ‘recycling’ is mostly used in this latter, more general sense.

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**Figure 1 Idealized aircraft life cycle**

- **Design**
- **Manufacturing**
- **Operation & Maintenance**
- **Parking**
- **End of Life**
  - **Decommissioning**
  - **Disassembly**
  - **Dismantling**
  - **Recycling**

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separation (air stream), Eddy current separation and magnetic separation. The materials are then sold to various recyclers. Before the reuse of the materials, flotation techniques can also be used to further sort them.

![Figure 2 Aircraft after the removal of landing gears](image2.jpg)

![Figure 3 Cockpit after the removal of avionics](image3.jpg)

This process description is mainly inspired by the process in place at Bartin's Chateauroux- and Bourges-based dismantling and shredding facilities; other companies might have slightly different modus operandi, although the outline should remain fairly similar.

The metals that can be recovered from end-of-life aircraft include notably aluminium, alloy steel, titanium and tungsten. Copper wires can also be sorted out. Aluminium is the main constituent of current EOL aircraft, present notably in the fuselage and wings. Tungsten can be found in the counterweights of some airframes. Certain dismantling companies can also cover metals present in smaller quantities, such as precious metals found in electrical connectors.

![Figure 4 Aircraft after interior stripping](image4.jpg)

![Figure 5 Aircraft scrapping with a shear crane](image5.jpg)

**RECOVERED METALS AND THEIR QUALITY**

For the moment, mostly bulk metals are extracted from end-of-life aircraft while rarer metals present in small quantities are often neglected. In addition, plastics and composites are not yet recycled at all (at least on an industrial scale) and end up in landfills or incinerators. The recovered metals are often of mediocre quality: for instance, EOL aircraft aluminium can contain a mix of different alloys (mainly 7000 and 2000 series) as well as smaller amounts of other metals such as steel and titanium found in rivets. Composite materials, plastics and textiles can also be found in the mix, especially if the aircraft interior is not completely removed before scrapping.

Greater use of manual dismantling could increase the quality of recovered materials; however, it would also increase the recovery costs, especially in countries where man-hours are expensive. There therefore seems to be a trade-off between dismantling costs and the quality of the recovered materials.

While spending more time on manual separation could potentially improve the quality of recovered
materials, it might also be possible to develop more sophisticated dismantling techniques relying on automation. For instance, a small drilling robot could be imagined for recovering the different types of aluminium, steel and titanium rivets found in aircraft. The whole dismantling process could also be reimagined in terms of reverse manufacturing where the aircraft is taken apart much in the same manner as it is assembled. This would optimise the quality of recovered materials. Of course, this type of a process might be difficult to apply to current EOL aircraft that were not designed with recycling in mind; however, future aircraft could be literally designed for recycling in order to maximise the recovery and reuse of EOL aircraft materials.

**PROBLEMS FACED BY AIRCRAFT RECYCLERS**

An important problem in the dismantling process is posed by various hazardous materials present in EOL aircraft. For instance, old military aircraft can contain asbestos, fire extinguishers contain Halon 1301 and smoke detectors and emergency exit signs found in commercial aircraft enclose radioactive elements. Hexavalent chromium can also be found in the aircraft paint primer. The correct management and disposal of these materials creates further dismantling costs.

The recycling of end-of-life avionics and electronics is another problematic issue. These parts can be shredded in waste electrical and electronic equipment (WEEE) shredders to try to recover precious metals and rare earths but the quality of the recovered fragments is far from optimal. The recycling of future aircraft alloys such as aluminium-lithium (Al-Li), aluminium-scandium (Al-Sc) and aluminium-magnesium-lithium (Al-Mg-Li) is another question that remains to be addressed. Currently, the presence of lithium creates an explosion hazard in the aluminium remelting phase and its presence in aluminium scrap is therefore undesired.

Last but not least, the logistic challenges of aircraft end of life are daunting: aircraft recycling can only become a non-niche industry when there are enough EOL aircraft concentrated in one area where they can be recycled. Consequently, it might be beneficial to establish global clusters where the recycling activities would be concentrated. Of course, mobile dismantling can provide another solution that can be applied to, for example, cleaning up the numerous desert areas where EOL aircraft are currently corroding away. However, the recovered metals must still be transported from these often remote areas to the recycling industry plants. It would therefore seem more optimal to have the aircraft make their last flight to a location where dismantling and recycling can be performed directly.

**END-USE APPLICATIONS OF RECOVERED ALUMINIUM**

Perhaps most importantly, high-value end-use applications for recycled aircraft aluminium (and other metals) are mostly missing: the recovered metals are often destined for downcycling. Old aluminium scrap can notably be used in ferroalloys or as an oxidant in electric steelmaking. The inferior quality of recovered aircraft aluminium is the main reason for its downcycling.

If different aluminium alloys or at least alloy families could be separated during the dismantling process, aircraft aluminium might be reused in commercial or personal vehicles, bicycles, construction and buildings or perhaps even in non-structural aeronautical applications. The presence of hexavalent chromium in the aluminium scrap poses some challenges to its reuse, notably in the packaging industry. There are techniques that might be used to remove the paint primer but their economic profitability as well as environmental impacts remain to be investigated.

**BUSINESS MODELS AND LEGISLATIVE CONTEXT**

The companies performing aircraft dismantling and materials recovery have several different business models. Some dismantling companies are actually MROs whose main activity is to repair aircraft, some have revenues that come mostly from parking and still others specialize in waste management, for instance in the collection and disposal of building and demolition waste and/or EOL vehicle and other metal scrap. The characteristic shared by nearly all the companies is that aircraft dismantling represents only a small side-line activity and does not bring an important share of the total revenue.

One of the major uncertainties in an activity based on the sale of recovered metals is the fluctuating metal prices. For instance, aluminium prices in the London Metals Exchange were cut in half as a result of the 2008–2009 economic crisis. One way to remedy this situation would be to guarantee a stable revenue to aircraft recyclers, for instance in the form of an eco-contribution destined to finance recycling activities. This type of fee should be big enough the finance a fair share of the dismantling activities while remaining small enough to represent only a small percentage of the price of an aircraft fresh from factory.
The legislative context of aircraft recycling is currently vague: there is no international or European legislation and individual countries are left to their own devices. There are, however, pieces of legislation (notably the Basel Convention and the OECD Control System for Waste Recovery) restricting transboundary movements of waste, such as EOL aircraft. In practice, aircraft recycling is often assimilated to vehicle recycling activities and the legislation from this field therefore applies. A clearer legislative context would surely improve the transparency of the field as well as facilitate international and European scale activities. A set of Best Management Practices for aircraft disassembly and recycling already exist since 2008 and 2012, respectively, thanks to AFRA [5].

**CONCLUSION**

There are many challenges as well as opportunities facing the aircraft recycling industry. The opportunities include notably the increasing number of EOL aircraft (creating economies of scale), improving dismantling technologies and techniques, greater environmental awareness and stricter legislation encouraging recycling practices. The European waste hierarchy already grants a privileged position to recycling and, in the future, there might be new pieces of legislation on the landfilling of composites or perhaps even an end-of-life aircraft directive, similarly to the end-of-life vehicle directive. Ideas of Extended Producer Responsibility, which inspired the ELV and WEEE directives, are also becoming increasingly popular [6]. The challenges of the recycling business are technical (for instance difficulties in mechanical and manual materials recovery and management of dangerous wastes) as well as logistic and labour- and market-related (high labour costs in Europe and lack of high value-added end uses for the recovered materials). The economics of aircraft recycling need to be clarified; perhaps an incentive such as an eco-contribution paid when purchasing new aircraft might be set up to encourage the activity.

In conclusion, there is a need for effective materials extraction and separation technologies, worthwhile end-use applications for the recovered materials as well as an attractive business model for aircraft recyclers. Only when all of these conditions are united can the aircraft recycling industry truly take off in Europe.

**REFERENCES**


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