The Aircraft at End of Life Sector: a Preliminary Study

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1 Summary

As with any product, an aircraft depreciates in value with time. The reduction in value arises from a number of factors including the increased cost of maintenance, repair and upgrading to comply with legislation. At some stage, maintenance, repair and upgrading become uneconomic and at this point the owner will consider taking the aircraft out of service. In many cases the retired airframe will contain valuable components and parts that can be returned to service via the second hand parts market. The second hand market is tightly controlled and parts returning to service must be accompanied by appropriate documentation. Failure to comply with national and international safety requirements can result in very significant fines.

The process of dismantling an aircraft at its end of life as an integrated airframe is referred to as parting-out. An aircraft may be parted-out while still fully certified and potentially revenue generating because the component parts of the aircraft become more valuable than the aircraft in flying condition.

The parting-out process is undertaken in phases as useful and reusable parts are progressively removed. The body owning the airframe at the parting-out stage may require that the engines, undercarriage, in-flight entertainment systems and some of the avionics are returned for future use. Following removal of these parts back to the owner, other useful parts are removed, catalogued and sold to specialist second-hand parts dealers. All parts are inspected and certified as usable, repairable or unfit for service, with the appropriate documentation. Second-hand parts suppliers tend to focus on particular aircraft types or makes.

Having removed all valuable components have, the remaining fuselage is broken up into small pieces and processed by a metal recovery company. The point at which sub-systems and materials cease to be “valuable” to the parting-out agency is dependent on the cost of removing them, the overhead associated with securing appropriate paperwork, and particularly the infrastructure and technology available to extract value. The legislative environment also affects the value (positive or negative) of the reduced airframe.

As aircraft manufacturers increase the composite content of commercial aircraft so the recycling of the shredded residue becomes increasingly difficult. When these airframes are retired, it is likely that the already difficult landfill regulations, especially in Europe, will put a high cost – or total ban - on disposal by this route. Further, should OEM take-back requirements such as those being introduced in the automotive sector in Europe in 2007 be extended to other products such as airframes, OEMs currently possess little know-how or experience in what to steps take. In general, OEMs in the aerospace sector have high levels of awareness of this scenario and are being proactive in seeking global solutions to end of airplane life issues. Airbus is evaluating the management of dismantling sites through its PAMELA pilot project that aims to demonstrate that up to 95% of the aircraft and its components can be recycled. Boeing has established a voluntary association, known as AFRA, to achieve a similar aim; but in this case through recommended end-of-life organisations and the distribution of best practice.

Science and technology plays a major role in determining the end of life value of an aircraft. Where value can be increased, an economic driver is created to increase the fraction of recovered, re-used or recycled materials. The infrastructure in Europe and the US is already in place to reuse/recycle more of the airframe if cost-effective dismantling and separation technologies were available, such as efficient separation of metallic materials including differentiation between aluminium alloys; carbon fibre extraction and re-use; avoidance of Pb, Cr and Cd in aircraft manufacture; robust smart tags; and more recyclable cabin interiors.

2 Aircraft at End of life

Like all products, civil aircraft eventually come to the end of their useful working lives. The reasons for this may include:

- Increasing maintenance costs
- Legislation demands expensive technology upgrades
- Difficulties in obtaining replacement parts
- Increasing content of time or service expired parts

The typical depreciation in value of an airframe is shown in Figure 1.

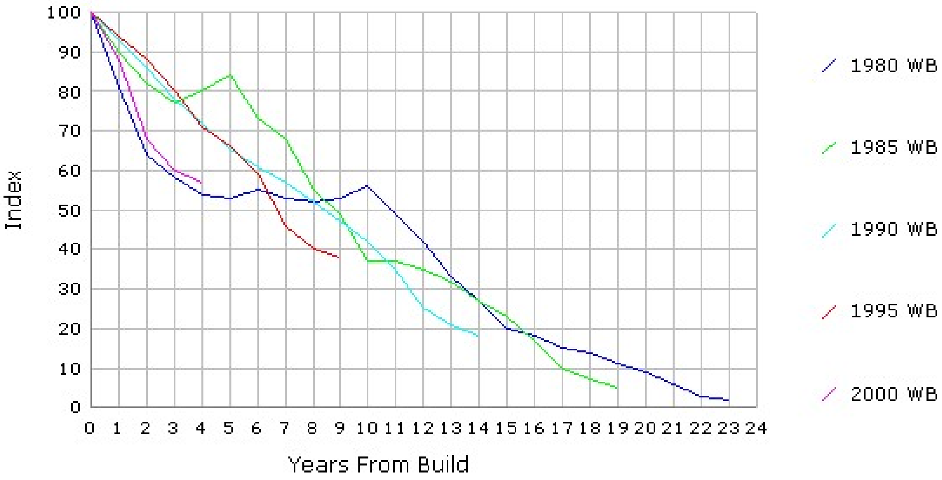


Figure 1. Wide Bodies (WB) Aircraft value as a function of age (wide bodied aircraft).
Source: Air Claims [1]

Figure 1 shows that a wide-bodied airliner built in 1980 has almost no value in 2007 even though it may be in flying condition. A similar trend is seen for all aircraft types irrespective of manufacturer. Consequently there is a point when the operating airline will take the decision that an aircraft is no longer worth retaining in service. This point will depend on market conditions and can be affected by fuel costs, depressed air travel during times of conflict, terrorism, or other concerns such as those seen due to the transmission of severe acute respiratory syndrome (SARS).

Figure 2. A Boeing 747 at Marana Air Centre, Tucson, Arizona, US.

Currently over 2,000 aircraft are in storage world-wide, and the number of military aircraft in storage is considerably greater. Over the next 20 years, approximately 5,000 commercial airliners are expected to be withdrawn or retired from service at a rate of approximately 250 per year. Compared with the automotive sector for example, these numbers and the overall materials volume is small. However unlike the automotive sector, the asset value of components and materials tied up in retired airframes can be very considerable. In Europe, there is also the consideration of the high cost of space to store airframes as well as adverse climate considerations that quickly undermine end of life value.

During outdoor storage, airframes slowly degrade to the extent that they eventually become environmental eyesores. For the OEM, this may present corporate presentation issues since the airframe almost always is still easily recognisable as, for example, a Boeing or an Airbus airframe. In a world where corporate identity and brand awareness has significant commercial value and importance, there is a growing reluctance for the OEMs to be associated with decaying structures.

Figure 2 shows a partly dismantled and decaying Boeing 747 in the US, and here as in many cases, the airframes can be viewed readily from public spaces. In this case the airline insignia is also visible, but in most cases this is removed by the airline so that it is not associated with the airframe. These issues and concerns are just one aspect of product stewardship that is becoming of increasing importance to airframe and equipment manufacturers and their suppliers.

3 WINGNet

WINGNet (Waste reduction IN aircraft-related Groups) is a network funded for two years by the UK Engineering and Physical Sciences Research Council (EPSRC). WINGNet is focused on the development of the technologies and infrastructure required to meet the challenges in the sustainable use and reuse of aircraft materials. The WINGNet scope of activities were formulated in consultation with the UK aerospace industry to identify critical materials science research required to improve the UK’s performance in sustainable use of materials. This report constitutes one of the WINGNet outputs and is intended for a non-expert in sustainable use materials working in the aerospace sector.

3.1 WINGNet objectives

- To examine and highlight fundamental materials science and techniques relevant to the development of new materials, recycling, remanufacture of components and reuse of materials in the aerospace sector.
- To identify technical opportunities for a series of high quality collaborative research proposals in the area of ‘Sustainable Use of Materials’.
- To improve the coordination within the UK aerospace sector on issues relating to the sustainable use of materials, involving key industries, academics, institutes, groups and trade bodies concerned with sustainable use of aerospace materials.
- To establish the current state-of-the-art in the manufacture and remanufacture of components and the reuse of materials, and to develop research strategies where the current state-of-the-art is deemed to be lacking.
- To bring together key personnel involved in the sustainable use of aircraft materials in an atmosphere conducive to open discussion.
- To update on related research proposals and programmes facilitated by WINGNet.
- To identify priorities for further research and activity.

3.2 Background

While the End of life Vehicles (ELVs) Directive 2000/53/EC places a significant burden on automotive vehicle manufacturers, with recycling and recovery targets of 85% and 95% respectively by 2015, no such directive applies to the civil aerospace industry. However, there is growing concern in the industry that a similar directive may be introduced. None of the world’s civil aerospace suppliers are technically prepared to meet the requirements of such a directive. Nonetheless, it has become clear through WINGNet consultations that the sector wishes to be proactive in the development of disassembly or parting-out capabilities and technologies that will contribute to the development of a more sustainable aerospace industry in the UK. In the absence of legislative drivers, projects and expenditure in this area have to be justified on the basis of economic benefit. Therefore, there exists an opportunity for the UK to develop aerospace-related end of life technologies that will establish the UK as a world leader in economic end of life technologies and processes.

4 Product Stewardship

Product stewardship is a product focused approach to environmental protection, also known as extended product responsibility (EPR). Product stewardship calls on manufacturers, retailers, users, and disposers to share responsibility for reducing the environmental impacts of products. Product stewardship recognizes that product manufacturers can and must take on new responsibilities to reduce the environmental footprint of their products. In most cases, manufacturers have the greatest ability, and therefore the greatest responsibility, to reduce the environmental impacts of their products. It could be argued that companies accepting the challenge are recognizing that product stewardship can also represent a business opportunity. By rethinking their products, their relationships with the supply chain and the end customer, some manufacturers can increase productivity, reduce costs, foster product and market innovation, and provide customers with more value at less environmental impact. Reducing use of toxic substances, designing for reuse and recycling, and creating take-back programs are opportunities for companies to become better environmental stewards of their products.

By taking responsibility for the whole life of a product the manufacturer can also go some way to preventing unauthorised use of its products and thus protect, maintain and/or enhance brand credibility. This is a particularly relevant aspect of product stewardship in the aerospace industry where part control and associated safety requirements must be stringent.

The concept of product stewardship focuses only on the manufacture of a product and subsequently its use and disposal. Therefore consideration of any environmental impact is restricted to those areas. In order to obtain a wider understanding of the impact of a product on the environment it is necessary to consider the life cycle impact of that product. Life cycle impact considerations include taking into account each stage involved in the manufacture of the product from obtaining the raw materials through to disposal, and where relevant, recycling or reuse. Life cycle thinking is considered in more detail later.

Unauthorised, or improper, use of a product is of great concern to high technology manufacturers where safety is a critical goal. For example, consider the theoretical case of a well-known supplier of aerospace gas turbines who sells a gas turbine to a user who then fails to maintain and service it according to the manufacturer's specification. This engine fails in service resulting in an accident involving fatalities. Even though the manufacturer had sold that engine to the user and had no direct involvement in its use, the incident and public news reports will always identify the manufacturer. Similarly, potential litigants may identify the OEM for damages, and investigators for prosecution. Thus manufacturers of safety critical components are actively considering leasing arrangements in preference to selling a product. In doing so the manufacturer retains control of the product, its use, maintenance and therefore exposure of the company to product liability claims. Such schemes are also equally driven by the preferences of the airlines, and examples include Rolls-Royce's "Power by the Hour" [2] and General Electric's engine leasing programmes [3].

In the EU, there is a growing volume of directives and legislation that is forcing manufacturers to think about their responsibilities in relation to the manufacture, use and disposal of their products. A selection of these directives includes the Waste Electrical and Electronic Equipment (WEEE), the Restriction of the use of Hazardous Substances (RoHS) and the End of life Vehicle (automotive) directives. The WEEE directive requires manufacturers to finance the cost of treatment and recycling of separately collected end of life equipment. The RoHS directive requires manufacturers of Electrical and Electronic Equipment (EEE) to find alternatives to lead-based solders, mercury, hexavalent chromium, cadmium and brominated flame retardants. The End of life Vehicle directive aims to allow the last holder of an automotive vehicle at its end of life to dispose it free of charge ("free take-back" principle) and the manufacturer must meet all, or a significant part of, the cost of applying this measure.

In the aerospace sector, the area of product stewardship was recently elevated in importance following a tipping incident involving a retired Ryanair Boeing 737-200. In this incident, published in The Courier in August 2005 [4], Ryanair had sold a number of aircraft to a US company for disposal at end of life. The US company subsequently sold some of the airframes for scrapping or salvaging, and parts of one of these were subsequently washed up on a beach near Methil docks in Scotland. The parts washed up included seats, oxygen masks, electronic components, safety cards complete with Ryanair logos and parts of a wing or fuselage.

However, the washed up fragments were not the result of a tragic accident as was at first feared, but the fly-tipping of the remains of one of the parted-out planes retaining Ryanair identification. Even though both Boeing and Ryanair had sold the airplane and all associated liability, the Scottish Environmental Protection Agency stated that "….Ryanair does have a responsibility to ensure that their planes are dealt with properly."

Figure 3. Parts of a fly-tipped Ryanair Boeing 737 at Methil docks.

4.1 Aeropace Product Stewardship

In the UK and Europe, the key principles of product stewardship in aerospace have been put forward by the Advisory Council for Aeronautics Research in Europe [5] in their October 2002 and 2004 documents and the Department for Transport's document on Sustainable Aviation (URN05/1251) [6]. These documents set the direction and priorities for achieving the goal of sustainable aviation. Product stewardship reduces the environmental impact of products by considering the entire lifecycle of a product and its components by:

- Minimising the amount and type of material used in manufacture
- Reducing or eliminating the use of toxic materials
- Extending product life by future proofing the design
- Minimising maintenance, repair and overhaul
- Minimising fuel/energy consumed during the product's life
- Providing routes to reuse, recycle or responsibly dispose of waste products

Product stewardship may also help a business maintain brand credibility by:

- Restricting the use a product can be put to
- Ensuring high quality maintenance
- Ensuring that inferior replacement parts are not used and that life expired parts are not illegally returned to service
- Ensuring proper disposal

Product stewardship also has a role to play in design through:

- The functionality of the product
- The materials used, their cost and environmental impact both in manufacture and disposal
- Designing in ease of repair and maintenance
- Extended product lifetime
- The energy used in manufacture of materials, components and sub-systems
- Transport costs and energy consumed

Product stewardship in use effects:

- Minimising maintenance, repair and overhaul
- Minimising energy consumption during use

Product stewardship at end of first life results in:

- Extraction of valuable components and materials
- Ease of dismantling to economically extract components and materials
- Ability to upgrade

Figure 4 shows a typical product stewardship process.

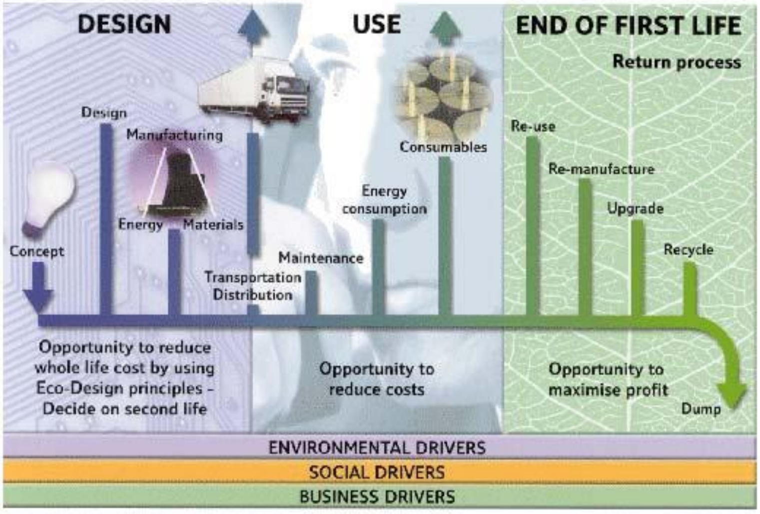


Figure 4: The product stewardship process.
(British Telecom)

4.1.1 Airframes

In the south-western United States, and elsewhere around the globe, there are large aircraft parks where retired or unused aircraft are stored. Some of these aircraft return to service, but many do not, and over time they degenerate into unsightly hulks. The product stewardship challenge the aircraft parks pose for Boeing, Airbus and other manufacturers is that although they do not own these aircraft, and have not done so for many years, passing members of the public (and possibly legislators) still see them as Boeing or Airbus products having a detrimental impact on the environment.

In order to address such issues airframe manufacturers are considering the establishment of centres where aircraft, any type or make, can be stored and properly maintained prior to re-entering service or can be disposed of in a manner that meets their required environmental practices and product stewardship aspirations.

Two industry led projects are examining these issues in detail: PAMELA is an Airbus initiative and AFRA is a Boeing initiative. Both are dealt with in some detail later but briefly:

- PAMELA (Process for Advanced Management of End of life of Aircraft) is an Airbus-initiated project to test environmentally-friendly recycling procedures with retired airliners. This initiative is supported by the European Union’s LIFE (l'Instrument Financier pour l'Environnement) programme. The objective of the €2.4 million PAMELA project is to ensure that end-of life aircraft do not end up visibly corroding and polluting airfields, degrading the environment and brand image. The project aims to demonstrate that between 85 and 95 percent of airframe components can be recycled, reused or recovered.

- AFRA (Aircraft Fleet Recycling Association) comprises a voluntary group of individuals and companies that have agreed to work in a cooperative fashion to provide full aircraft product life cycle capability.

4.1.2 Aeroengines

Aeroengine manufacturers have concerns over the maintenance and use of their products after sale, particularly as products progress beyond first ownership, since once an engine is sold the OEM supplier may no longer be responsible for its maintenance and use. But similarly to the case of airframes, in the event of service problems, the OEM may nonetheless be held responsible in perception and/or real terms. As previously mentioned, this chain of responsibility is leading to the development of “total care” packages whereby the OEM retains ownership of the aeroengine and can address product stewardship issues. These packages may include items such as:

- Line maintenance replacement parts
- Scheduled and unscheduled engine maintenance

- Life limited part replacement
- Incorporation of service bulletin requirements
- Availability of unit exchange line replaceable units
- Continuous spare parts replenishment.

At end of life, the OEM can ensure that products are properly removed from service, that life limited parts do not re-enter the supply chain, and that valuable materials and components are recovered.

4.1.3 Future Issues

New technologies, materials and manufacturing methods introduced into new products will increasingly reduce the environmental impact of products and assist in the responsible disposal of those products. In the automotive sector, there has been much discussion of adapting design for disassembly principles in order to ease recycling and disassembly. In the aerospace sector, this has not been regarded as a key customer requirement – not least because of the need to meet strict safety requirements for product robustness. Nonetheless, as with any complex product, the difficulty of disposal and re-use increases with the number of different materials employed, and this is particularly the case for polymeric and composite materials increasingly used in all parts of the transport sector. Therefore, rather than significant adoption of design for disassembly philosophies in the aerospace sector, it is more likely that there will be increasing emphasis placed on materials and structures research and development programmes. These programmes aim to rationalise the number of materials used. This rationalisation is certain to include targets to remove as many toxic and environmentally damaging materials as possible while maintaining the highest possible safety standards.

Shorter-term challenges are presented by the many thousands of older civil and military airframes still flying but approaching the end of their useful life. These airframes and their engines often comprise many disparate materials, the attitude to which in terms of their environmental impact and responsible disposal has changed dramatically since their manufacture. As these aircraft come to the end of their useful lives, techniques and technologies are needed to ensure that maximum value can be extracted and high environmental impact materials are disposed of responsibly. In this respect, there is a pressing need to identify best-practice from the disparate parting-out chain and to seek consensus in applying this best practice across the sector. This is a common aim of the PAMELA and AFRA projects.

5 Life Cycle Thinking

The concept of life cycle thinking, from raw materials extraction, through manufacture, use and maintenance to final end of life options facilitates an important shift in how industry has traditionally viewed itself and its operations. Life cycle analysis is a major topic in its own right, not discussed in any detail here, and its approaches are applicable across all industries including the aerospace sector. The ability to ensure that changes to design and/or operational procedures can reduce the total impact on the environment, as opposed to simply transferring the burden to another stage of the life cycle, is essential to life cycle thinking. The wider perspective required by life cycle thinking, in conjunction with producer responsibility or product stewardship, as previously described, creates a requirement to redefine some aspects of the relationships between different links in the supply chains. Only with more transparent relationships between links and new instruments to measure environmental impact within each link can opportunities for forging new relationships within the industry be achieved.

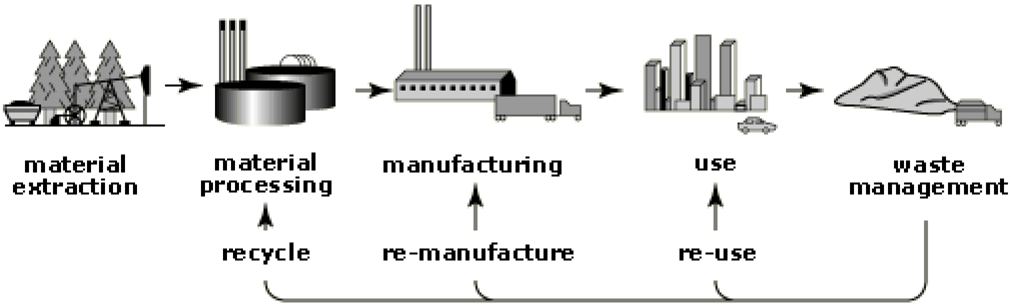


Figure 5. The life cycle of a product [7]

The life cycle of a product is shown in Figure 5 and shows five distinct links, all of which of course interact with the environment. In the vast majority of cases, and particularly in aerospace, the environmental impact of the use phase is the largest.

6 Parting-Out of Retired Airframes

The process of parting-out an airframe involves the dismantling of that airframe down to its component parts. The reasons why an operator may wish to do this is varied but can include:

- Old aircraft being taken out of service to be replaced by newer models
- Removal of aircraft from revenue service because they no longer meet international operating regulations and it is too expensive to upgrade
- Aircraft damage sustained during operation is uneconomical to repair
- Scarcity of spare parts for that particular aircraft result in the sum of the individual parts having more value that the flying aircraft
- Cannibalisation of an aircraft to keep others airborne

The International Society of Transport Aircraft Trading (ISTAT) defines "Parting-out Value" or "Salvage Value" as: the actual or estimated selling price of an aircraft, engine or major assembly based on the value of marketable parts and components that could be salvaged for re-use on other aircraft or engines.

Thus parting-out becomes advantageous, over storage, when disassembly for parts would most probably result in the highest cash yield for the asset "as-is" as compared with the market value of the asset as a whole. When considering storage, the on-going cost of that storage and required maintenance must be considered.

The salvage or parting-out value should not be confused with scrap value which is the actual or estimated market value of an aircraft, engine or major assembly based solely on its metal or other recyclable material content with no saleable reusable parts or components remaining.

Any European based company or individual wishing to part-out an airframe with a view to salvaging, for aerospace use, parts and components must be registered under EASA (European Aviation Safety Authority) Form 145 [8]. In addition, parts returning to service must be accompanied by EASA Form One [9] that specifies clearly the part, manufacture, part number, its service condition and a history of servicing or repair. Thus each part should be accompanied by a paper trail that itemises the history of that part. The responsibility for checking the conformity of a part rests with the owner. In Europe, parts suppliers are encouraged to become members of The European Aviation Suppliers Organisation [10] that is run by its members.

6.1 Parting-out of a Boeing 757

How an aircraft may be parted-out can be illustrated by considering a Boeing 757 that was parted-out by a leading UK based specialist company. In this case, the B757 (figure 6) was worth more as parts than as a flying revenue generating aircraft because owing to the shortage of second-hand B757 parts for this aircraft type. This is not true for all makes and types of aircraft.

Prior to parting-out the aircraft had been operated by a leading tour company on revenue service. Having decided the aircraft was no longer required, the tour company returned it to the leasing agent who put it up for sale. It was purchased by a second-hand parts company, without its engines as these were retained by the leasing agent. The parts company issued a contract to dismantle the aircraft and to remove, in accordance with manufacturers' instructions, and catalogue reusable parts (rotable parts) on its behalf. Typically these parts will have included avionics, pumps and electric motors, hydraulics, in-flight entertainment systems, undercarriage and aerofoils.

Figure 6. Parting out of a Boeing 757 at Lasham Airfield, Hampshire, UK

The aircraft was flown into Lasham airfield in Hampshire where the disassembly took place. The engines were removed and returned to the leasing agent as requested. After all rotables were removed the remaining carcass, comprising mainly the fuselage, wings, tail structure and internal fittings were transferred to the specialist dismantler for sale and disposal. Items such as the cabin doors and flight deck were salvaged and sold for training purposes. The remainder was sold as scrap to a metal smelter and the plastic cabin furniture was sent to landfill.

On completion of the parting-out/scrapping procedure, ASI returned the relevant paperwork to the leasing company and provided them with a certified disposal certificate confirming that the aircraft had been disposed of in accordance with legislation.

6.2 Part Control

The competitive pricing of air travel increasingly puts pressure on airlines to cut the cost of maintenance and repair. The temptation to use "cheap parts" is growing in regions where regulation, inspection, enforcement and penalties for transgression are weak. Investigations have shown that "cheap parts" i.e. parts and components that do not meet the manufacturers' quality standards and are not approved by them, or parts that do not have the correct associated paperwork have been found in a considerable number of aircraft.

The second hand market for aerospace parts and components can be highly lucrative and there is a driver for unscrupulous businesses and individuals to sell unserviceable, damaged and time-expired parts. For example, in May 1998, the U.S. Department of Transportation's Office of Inspector General announced that a company had pleaded guilty and agreed to pay a $3 million criminal fine and $2 million in restitution for falsifying records pertaining to the origin of parts removed from two Boeing 727 aircraft [11]. In this case, more than 3,000 parts were removed from the aircraft and were transferred to a parts sales company. Equipment transfer tags identified that some parts were in serviceable condition under Federal Aviation Administration (FAA) regulations and could therefore be installed in commercial aircraft holding U.S. airworthiness certificates without further inspection or testing. The tagged parts included gyros, main landing gear assemblies, steering computers, navigational computers and other flight critical parts. These parts had in fact not undergone all the procedures required for tagging and re-entry into service.

Consequently it is imperative that the flow of used parts are controlled and documented, and that unserviceable and time-expired parts are properly removed from the supply chain. These aims and objectives are fundamental to the AFRA and PAMELA projects.

In the military sector, parting-out of retired airframes may also bring various restrictions on the final destinations of components, equipment and sub-assemblies since even relatively old airframes may contain designs, materials, embedded know-how, systems, etc that are technologies controlled by sovereign governments. Even relatively small items of a dismantled airframe could provide useful information to an enemy. Evidently part control is again of paramount importance.

6.3 The Parting-Out Chain

Storage of an airframe in flying condition is expensive since the airframe will still be required to undergo regular safety and maintenance checks. These aircraft may remain in storage for a considerable time before being sold on to a new operator, and therefore the current owner can incur significant storage and maintenance charges. An alternative option for the owner is to consider parting-out the airframe. To help owners and operators make sound business decisions regarding continued storage, parting-out or scrapping, the owners need a good understanding of:

- The current market value of the type being considered
- Market trends for the type
- The demand, and hence value, of the parts market for the type
- The costs involved in parting out versus the cost of storage and maintenance

The relationships and interplay between the various players involved, once the parting-out option has been chosen, are shown in Figure 7. The key player in the parting-out process is the regulatory bodies as they are responsible for air safety and have a duty to ensure that the rules and regulations relating to the reuse of second hand parts are strictly controlled.

Parted-out or scrapped aircraft and parts must be documented according to CAA notice AN 96 [12] that states: *"The purpose of this Airworthiness Notice is to provide information and guidance to persons involved in the maintenance, sale, or disposal of aircraft parts. It provides information and guidance to prevent scrap aircraft parts and materials from being sold or acquired as serviceable parts and materials."*

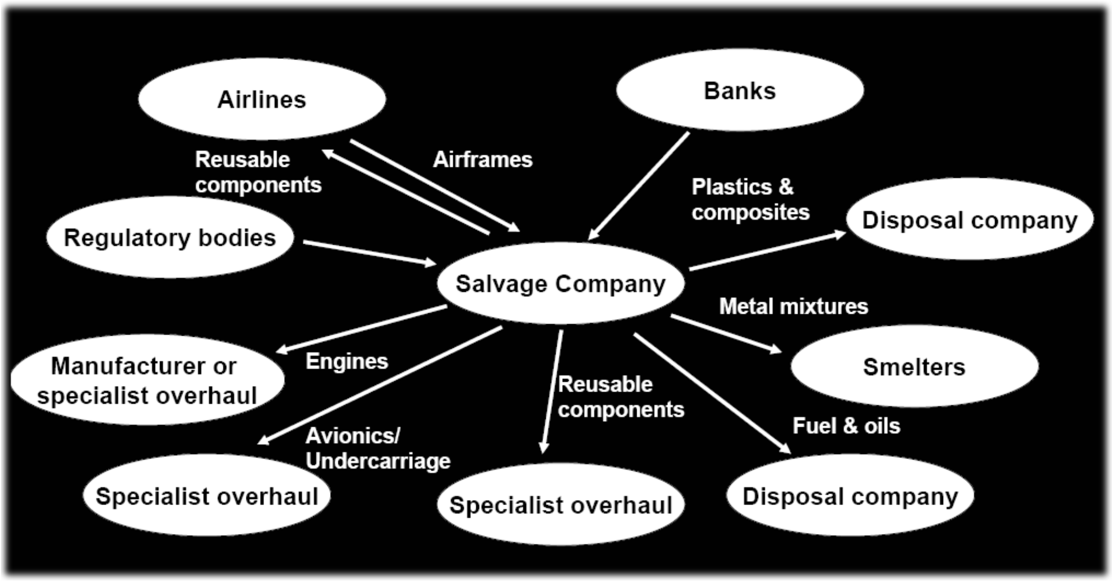


Figure 7. A schematic representation of the various parties involved in the aerospace parting-out chain

Most often the salvage or parting-out company will be contracted by the airframe owner to undertake the parting-out. Only in a few cases will the parting-out company purchase an airframe themselves. The airframe owner will usually be an airline, leasing company, a bank or similar. As part of the parting-out contract, the airframe owner will usually specify those parts they require to be returned for future use, and these will often include the engines.

On removal, the rotable parts are catalogued, part numbers checked against the aircraft's logged inventory, and the parts inspected and recorded as being fit for immediate re-entry into service, in need of service or repair or unserviceable. If the part is unserviceable or irreparable, it is normally destroyed, or rendered unusable - to ensure it does not find its way back into service. Serviceable or repairable parts are sent onto a parts supplier. Some major parts may be sent to a specialist company that undertakes a major overhaul, such as the engines or the undercarriage. In the case of engines, they can be kept in storage for considerable lengths of time if properly sealed and stored. If not, then after 6 months of storage the engine will require recertification. Procedures for the storage of engines are provided by the manufacturers. Figure 8 shows a part availability report available on-line.

Materials such as residual fuel and oils are not permitted to re-enter the aviation sector and are usually disposed of by specialist companies or, in the case of fuel, used on-site as an energy source. Interior plastics and linings are usually sent for landfill and the aircraft carcass is chopped up and then taken to a metal smelter.

6.4 Part Suppliers

Part suppliers usually only cater for specific aircraft types or types or part e.g. undercarriages. The list below, which is not exhaustive, gives an idea of this specialisation:

Boeing Parts Page
http://www.boeing.com/commercial/spares/part_page.html
Provides an easy and efficient way to research, quote, order and track parts from Boeing Spares

Avtrade
(http://www.avtrade.co.uk/)
Supports Boeing, Airbus and BAE Systems fleet types. Holds over 500,000 rotable and expendable line items. Full traceability is guaranteed on all components, and all rotables are supplied with current JAR/FAR release from approved workshops.

Bramlands Aviation Ltd
http://www.bramlands.com/
Supports SAAB 340 aircraft

Aerospace Support Associates
http://www.asa.uk.com/
Offers a comprehensive spares service, are proficient in providing "kits" covering, engine change, B & C checks etc

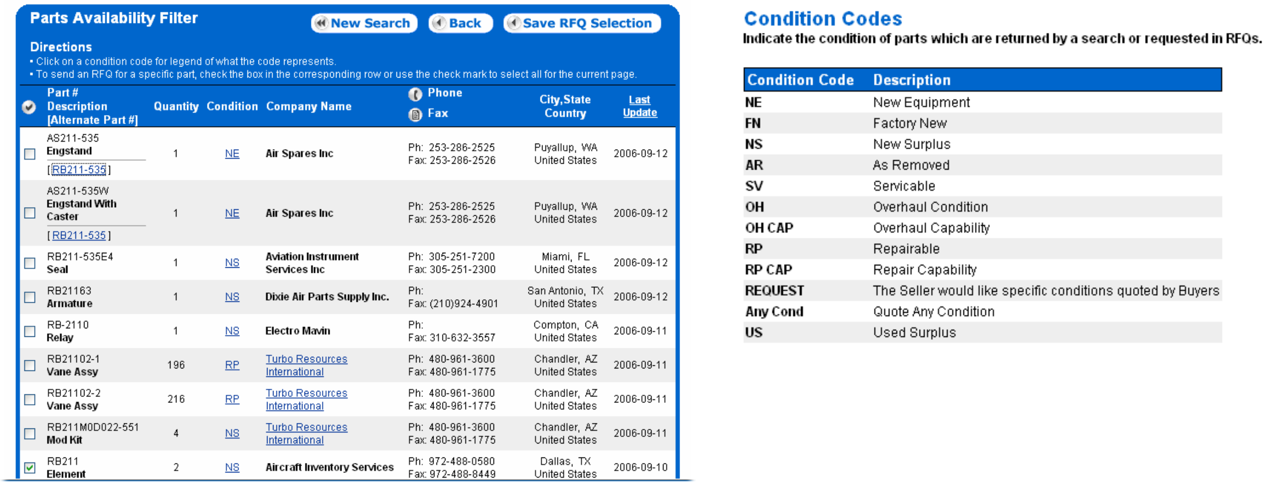
Aerotron
http://www.aerotron.co.uk/
A320, A330, MD80, DC10, Boeing 757, 767 and helicopters.

Burwood Aviation
http://www.burwoodaviation.co.uk/
Has established links with airlines and maintenance bases, e.g. Thomas Cook, Monarch, British Midland and KLM.

Ansett Aircraft Spares and Services
http://www.ansettspares.com/
Based at Heathrow but have sales and stores in California and Australia. Have large stocks of BAE expendables.

Inventory Locator Services
http://www.ilsmart.com/
ILS is a web based parts portal. Over 5 billion parts listed, 50,000 customer accesses the site each day.

Parts Logistics
http://www.partslogistics.com/
Parts Logistics, buy, sell, locate, and research aircraft parts, helicopter parts, electronic parts, marine parts, industrial parts, and defence related equipment. An example of a typical search report is provided in Figure 8, showing a description of the part, its part number, the condition of the part and the current owner.



Directions

- Click on a condition code for legend of what the code represents.
- To send an RFQ for a specific part, check the box in the corresponding row or use the check mark to select all for the current page.

✓	Part # Description [Alternate Part #]	Quantity	Condition	Company Name	Phone Fax	City,State Country	Last Update
☐	AS211-535 **Engstand** [RB211-535]	1	NE	**Air Spares Inc**	Ph: 253-286-2525 Fax: 253-286-2526	Puyallup, WA United States	2006-09-12
☐	AS211-535W **Engstand With Caster** [RB211-535]	1	NE	**Air Spares Inc**	Ph: 253-286-2525 Fax: 253-286-2526	Puyallup, WA United States	2006-09-12
☐	RB211-535E4 **Seal**	1	NS	**Aviation Instrument Services Inc**	Ph: 305-251-7200 Fax: 305-251-2300	Miami, FL United States	2006-09-12
☐	RB21163 **Armature**	1	NS	**Dixie Air Parts Supply Inc.**	Ph: Fax: (210)924-4901	San Antonio, TX United States	2006-09-12
☐	RB-2110 **Relay**	1	NS	**Electro Mavin**	Ph: Fax: 310-632-3557	Compton, CA United States	2006-09-11
☐	RB21102-1 **Vane Assy**	196	RP	Turbo Resources International	Ph: 480-961-3600 Fax: 480-961-1775	Chandler, AZ United States	2006-09-11
☐	RB21102-2 **Vane Assy**	216	RP	Turbo Resources International	Ph: 480-961-3600 Fax: 480-961-1775	Chandler, AZ United States	2006-09-11
☐	RB211M0D022-551 **Mod Kit**	4	NS	Turbo Resources International	Ph: 480-961-3600 Fax: 480-961-1775	Chandler, AZ United States	2006-09-11
☑	RB211 **Element**	2	NS	**Aircraft Inventory Services**	Ph: 972-488-0580 Fax: 972-488-8449	Dallas, TX United States	2006-09-10

Condition Codes

Indicate the condition of parts which are returned by a search or requested in RFQs.

Condition Code	Description
NE	New Equipment
FN	Factory New
NS	New Surplus
AR	As Removed
SV	Servicable
OH	Overhaul Condition
OH CAP	Overhaul Capability
RP	Repairable
RP CAP	Repair Capability
REQUEST	The Seller would like specific conditions quoted by Buyers
Any Cond	Quote Any Condition
US	Used Surplus

Figure 8. Part availability report from Parts Logistics with condition key

7 Technology Trends and Challenges

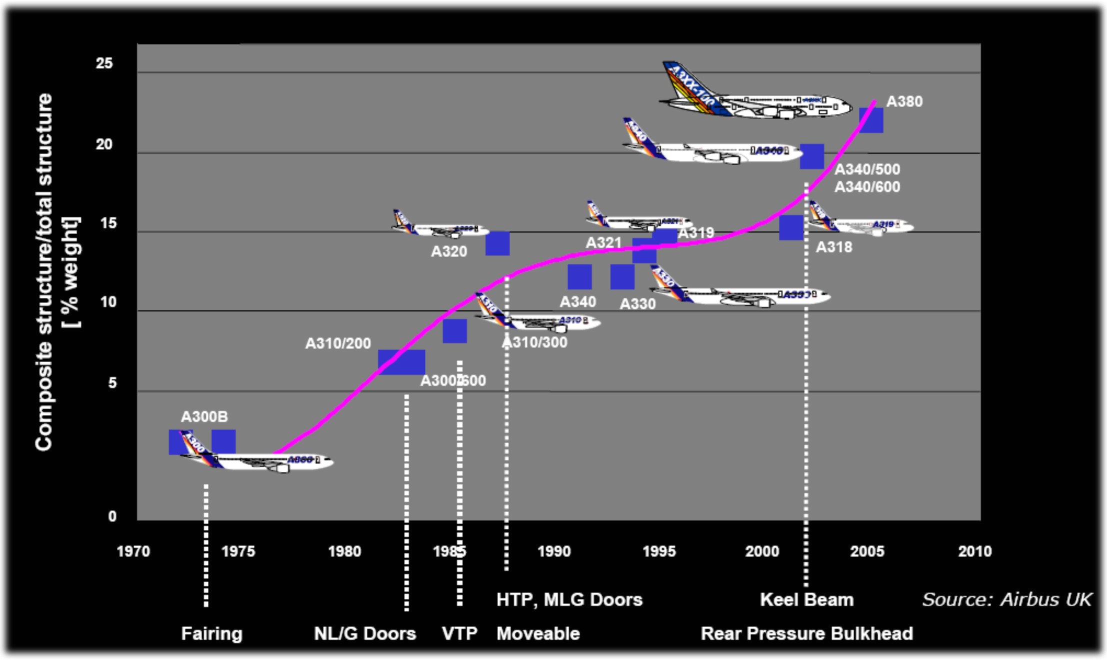
7.1 Composites and Composite Recycling

Aerospace composite recycling is increasingly important owing to the rapidly increasing use of these materials in the commercial aerospace sector. Future products from Airbus, Boeing, Embraer, etc are announced to use up to 50% unladen weight of polymeric based composites in their primary structures. These type of materials currently pose very significant recycling and recovery challenges. One major airframe dismantler in Europe commented: "if asked to dispose of a 787 today we would have to dig a very large hole and bury it." Evidently, the end of life problems concerned with composites are set to increase and new approaches and technologies to resolve composite end of life problems must start to be developed now. The increased use of composites is driven by weight reduction, reduction in the number of components, reduced maintenance costs and potential improvements in fatigue behaviour. It has been suggested [13] that by 2020, the use of composites will give production aircraft of that date a fuel burn advantage of between 10% and 15% over their year 2000 counterparts.

The land-filling of waste or end of life composites is no longer a commercially viable option as various European directives are forcing manufacturers and suppliers to accept responsibility for recycling end of life wastes. These directives include:

- Council Directive, 1999/31/EC on landfill waste
- Council Directive, 2000/76/EC on incineration of waste
- Waste framework directive, 75/442/EEC
- List of waste, (LoW) 94/3/EG
- Hazardous waste directive, 91/689/EEC
- Harmonisation of waste reduction programmes directive, 92/112/EEC
- Shipment of waste directive, 120/97/EC
- Municipal waste incineration directive, 89/369/EEC and 89/429/EEC
- Harmonisation list of waste, com.dec.2000/532/EC

In Europe approximately 150,000 tonnes of new fibre reinforced plastics were used last year.



Source: Airbus UK

Figure 9. Increasing use of composites in Airbus aircraft

Figure 9 shows the increasing use of composites in Airbus aircraft with the early A300 model utilizing less than 5% while the new A380 comprising in excess of 20%. The upper fuselage section and horizontal tail section of the A380 super-jumbo will be manufactured from the GLARE (a glass fibre and aluminium composite) material. One of the major reasons that GLARE was chosen is its resistance to fatigue crack growth and a density reduction of 10% compared to conventional aluminium alloys. Carbon fibre reinforced plastic (CFRP) composite is also used widely, for example for the central wing box and in parts of the fuselage. The vertical fin box, rudder and elevators, the upper-deck floor beams and rear pressure bulkhead are also made from CFRP composite.

The Boeing 787, scheduled to start flight testing in 2007/2008, is a smaller aircraft than the A380 and is designed to carry approximately 300 passengers. The B787 materials design is based substantially on carbon fibres in an epoxy resin matrix for the fuselage and a composite wing. New production techniques have been developed to produce the composite fuselage, including composite fuselage sections 6.7m long and nearly 6m wide, as shown in Figure 10.

The 787 forward fuselage composite barrel autoclave at Kawasaki, Nagoya, Japan. Source: James Wallace/Seattle Post-Intelligencer

A cured 787 fuselage barrel section

Figure 10. Some of the composite technology developed for the Boeing 787 fuselage

Approximately 50% of the unladen weight of the Boeing 787 will comprise composites, as shown in Figure 11. Other civil aerospace use of composites include the rapidly growing business jet market, such as the business jet shown in Figure 12.

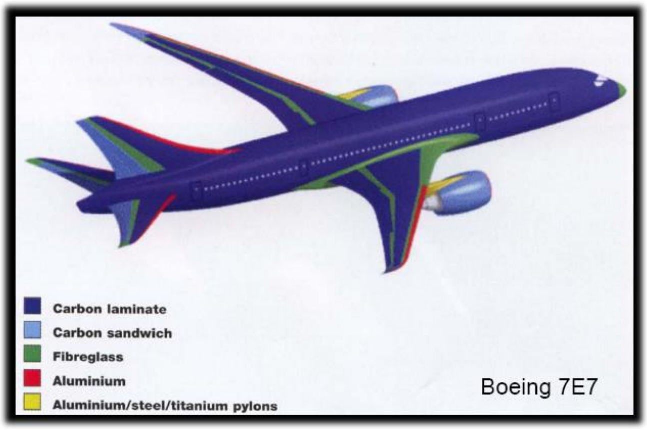


Figure 11. Composite use in the Boeing 787

Figure 12. Honda Business Jet with Carbon Composite Fuselage [14]

The business jet market is expected to require up to 24,000 new jets [15], very light jets through business jetliners over the next 20 years and all are expected to contain significant amounts of composites in their construction. For example the fuselage of the Honda business jet in Figure 12 is 100% carbon fibre reinforced composite.

Rotary aircraft, military aircraft (rotary, trainers, fighters, bombers and transports) and unmanned air vehicles of all types contain significant amounts of composites and the proportion of composites in these types is expected to continue to rise.

For many years, composites manufactured using thermosetting resins were considered to be non-recyclable, and some sectors of the plastics industry still consider this to be the case. Also, because disposal by land-fill was an easy and cheap option when the products were conceived, recycling did not need to figure highly in user and producer thinking. In the early 1990s, some companies in the thermosetting sector began to recognise that market pressures were demanding that these materials should be recycled or recovered rather than being land-filled upon completion of their life cycle. These factors, combined with user and public awareness, and not least increased landfill charges, have resulted in increasing efforts to find commercially viable routes to recycling composites manufactured using thermosetting resins.

There are now a number of European funded research projects looking to develop commercially viable routes to recovering carbon fibres from thermoset composites such as the work undertaken at INASMET Tecnalia [16] in Spain. This work investigated three potential recycling techniques:

1. a nitric acid treatment to dissolve/remove the thermoset resin
2. thermal pyrolysis
3. an incineration process

The conclusion of this work was that, on environmental grounds, only the pyrolysis technique should be considered on the large scale, and that the quality of the recovered carbon fibre residue was sufficiently high that the fibres should be considered for re-use. A major airframe manufacturer has suggested that recovered carbon fibre from one particular pyrolysis process was of sufficient quality that it could potentially be used in other aerospace applications.

Studies on composite recycling have also taken place at Nottingham University, UK in collaboration with Milled Carbon Ltd [17]. Milled Carbon have developed a pyrolytic process that can continuously recycle cured and uncured carbon fibre composite parts of up to 2 meters wide, 250 mm in height and thicknesses up to 25mm. The technique is applicable to manufacturing off-cuts or unused rolls of pre-impregnated material, as well as formed parts.

An alternative process for the recovery of carbon fibre from composites uses a low temperature liquid process that digests the organic resin leaving the fibres intact, and is being developed by Adherent Technologies in the USA [18]. This process involves the use of a highly acidic medium to digest the organic polymer matrix.

Even if reusing recovered fibres or in aerospace applications is not possible, there are other potential uses in the automotive, construction and marine sectors. Currently carbon fibre containing composite manufacturing waste of end of life material places a disposal cost on the responsible organisation. Any technologies that could reduce this cost, or in the best case scenario, convert the financial drain associated with composite "waste" material into a valuable material resource, will find rapid commercial application. This would stimulate the recycling and re-use of composites independently of any legislative drivers. The economics of such an approach at the current time are particularly favourable since the rapid uptake of composites is leading to; high prices for newly produced carbon fibre and some restriction in availability.

7.2 Cabin Interiors

How to deal with cabin interiors at upgrade and end of life is a concern for both the airframe disposal companies and operating airlines. Cabin furnishings are made up of a range of materials that are mostly plastic or composites based on polymers, and are often intimately inter-mixed. Currently the only option is to send these fittings to landfill. As already stated, this is an increasingly expensive option.

What to do with retired the cabin interiors is also a problem for airlines as they schedule cabin improvements and upgrades. The cabin fittings for a Boeing 737 weigh about 5 tonnes and those for a Boeing 747 approximately 10 tonnes. Typically an airline such as British Airways will schedule a cabin maintenance programme after 4 to 5 years in service and a full cabin upgrade (complete replacement) every 10 years. For an airline with 250+ aircraft, cabin disposal will become an increasingly important issue.


Figure 13. The cabin of a Boeing 757 during parting-out

As it is necessary to remove cabin components by hand some degree of sorting can potentially be carried out at the time of removal, this is very different from the automotive sector. During any year, a major established airline with a fleet of 250 or so aircraft may have as many as 25 aircraft undergoing cabin upgrading or complete refurbishment. This represents several hundred tonnes of material.

Some of the challenges here include:

- Efficient Separation of organic materials from metallic and composite materials
- Identification of the different classes of material, metals and non-metals
- Developing efficient and commercially viable re-processing technologies
- Finding suitably high value markets for the recovered materials

7.3 Metal Separation Technologies

Having removed high value components and materials from an airframe the remainder is broken up into small pieces and sent to a metal smelter for processing. Because of the mixed nature of this feedstock its value is low. However, many of the alloys and materials comprising this feedstock have significant value if they could be readily separated into purer materials streams.

This can be achieved to some extent. EMR Ltd (European Metals Recycling Ltd) use standard technology to separate out ferrous and non-ferrous metals and then use a series of floatation chambers to separate out metals having significant density differences. Further metal differentiation is undertaken using laser-sorting technology [20].

However, in order for recovered metals such as aerospace grade aluminium alloys to regain entry into a high value supply chain further automatic sorting into something approaching alloy types is needed.

In addition, recovery of copper from the extensive cabling within an airframe would add value to the total materials recovered during the parting-out process.

7.4 Replacement Technologies for Toxic Metals and Coatings

Current environmental legislation restricting the use of toxic metals in the manufacturing and automotive sectors is making the continued utilisation of metals such as lead, cadmium and hexavalent chromium increasingly problematic for other sectors. In the aerospace sector, attempts to find replacement technologies have not met with widespread success. Although the aerospace sector is largely exempt from some of these directives related to products on safety grounds, it is inevitable that eventually the aerospace sector will have to comply similarly; either through new targeted legislation, because of public pressure, or because since the aerospace sector represents typically <1% of the global market by value, the materials may cease to be widely available as the supply chain adopts other solutions. Of particular concern to the aerospace sector is any ban on the use of Cr(VI), Cd and Pb since underpinning understanding in and commercial confidence of alternatives does not exist. While considerable research into Cr(VI), Cd and Pb replacements has been conducted in a variety of commercial fields, these studies often do not have relevance for aerospace applications; where aerospace-related studies exist, they generally fail to provide sufficiently compelling performance to justify the costs of component re-qualification.

The ELV directive for the automotive sector came into effect on July 1st 2003 and one of its provisions restricts the content of Cr(VI) in corrosion preventing coatings from July 1st 2007 onwards to a maximum of 0.1% (w/w) per homogeneous material. The WEEE directive imposes responsibility on manufacturers for the disposal or recycling of their electrical or electronic equipment, although WEEE is currently only applicable to consumer goods. The US is introducing "RoHS-equivalency" measures, for example in California where it is now prohibited to manufacture electrical/electronic goods that could not be sold in the EU. Unofficial notes of the RoHS Technical Adaptation Committee (TAC) proposed maximum concentration values of Pb = 0.1%, Cd = 0.01%, and Cr(VI) = 0.1% by weight in finished goods. Although the EU Commission's Legal Services have suggested an RoHS exemption for Cr(VI), Cd and Pb (as well as others) in electrical equipment for the aerospace industry, the onus has been placed on the producer to supply all necessary independent scientific evidence to the TAC to support a specific exemption application on safety grounds.

Cr(VI) containing processes are applied to the overwhelming majority of Al-based aerospace components, including the airframe, wings and ancillary honeycomb panels, and are also used to protect electrical and electronic components. The three main uses of Cr(VI) are in chromic acid anodising (CAA) processes, chromate conversion coating (CCC) processes, and as strontium chromate primer (SCP) in bonding applications. SCP replacement is currently the focus of research by major adhesive manufacturers. In 2005, Boeing stated that replacing Cr(VI) in the above processes is one of the key aims of their Pollution Prevention (P2) Group. The Joint Group on Pollution Prevention (JG-PP, USA) recently initiated a Joint Test Protocol (JTP) on Cr(VI) avoidance for defence and aerospace platforms. In Europe, there have been a series a consortium based R&D projects addressing these same issues. All of the above projects have focussed on screening and evaluating existing technologies developed elsewhere rather than developing new processes.

Cd coatings are routinely used on aircraft for the corrosion protection of vast numbers of fasteners, electrical components and electrical connectors. There is general consensus that there is no single replacement for Cd that fulfils all of its inherent properties/functions: barrier protection against corrosion; sacrificial protection on ferrous substrates; galvanic compatibility with Al and its alloys; good surface lubricity; low volume corrosion products; low electrical resistance; and a solderable surface.

Pb is used extensively in Pb-based solders for electrical connections on printed circuit boards and printed wiring boards. Pb-free solder is the most commercially advanced of the toxic metal replacement problems investigated here, and commercial products are available. However, commercial Pb-free products have been developed for non-aerospace sectors and are of limited use in understanding / predicting lifetimes in the much harsher aerospace environment, where there are more severe combined effects of creep during thermal cycling, mixed frequency vibrations, higher and/or lower service temperatures and extreme temperature differences. A key concern of the aerospace sector (and all other sectors) is inter-connect reliability. Fully numerical as well as empirical and semi-empirical approaches based on Coffin-Manson fatigue correlations are used generally to understand/predict solder joint lifetime but lack sophistication to account for the harsher aerospace environment. A particular concern is that as Pb-free is adopted everywhere in mass market electronics, there is no Pb-free drop in replacement for Pb containing solders for the harsher aerospace environment. The most popular tin-silver-copper (SAC) alloys that are drop in replacements in domestic electronics suffer from slow stress relieve (slower creep) under wide temperature fluctuations in aerospace environments, hence thermal mismatch strains are retained, and leading to premature failure.

Therefore in the area of these three toxic metals, the sustainable materials community faces major tasks to identify new material solutions that offer the – probably unmatchable – performance of incumbent solutions. While the timetable for the emergence of such solutions is unclear and despite the lack of penetration of R&D to date, new ideas for toxic metal replacements should remain on the sustainable materials roadmap.

7.5 Materials Identification Tags

The development of embedded material identification tags would be highly beneficial to the aircraft scrapping sector. Although material tagging is not new, it is widely used in the polymer sector; there are potential issues when applied to safety critical components. In the case of turbine blades any, tagging would have to have no negative impact on the safe and reliable operation of the blade during use. Bar coding has been used in the steel industry [20]. However, here the codes are often on attached plates rather than on the material itself. This would not be possible in the case of a turbine blade, although it may well be applicable on other metallic components.

Such a tagging scheme should allow materials to be separated into higher value feedstock streams.

8 PAMELA (Process for Advanced Management of End of life Aircraft)

PAMELA [21] is an Airbus initiated aircraft recycling project funded by the European Commission's LIFE Environment Programs (L'Instrument Financier de l'Environnement). The aim of the 2.4 million euro project is to make sure that end of-life aircraft such as thirty year-old A300s do not end up degrading on the sides of airfields. The project’s objective is to demonstrate that 85 to 95 percent of aircraft components can be easily recycled, reused or recovered. Equipment and products such as the electronics system, tyres, batteries, CFC (chlorofluorocarbon) and hydraulic fluids from aircraft have to go through a controlled processing channel. Also serviceable, working spares and components recovered from end of life aircraft will be catalogued and tracked as they are put back into the second hand parts supply chain. PAMELA will also help launch a European network to disseminate information about commercial airframe dismantling at their end of life.

Airbus and its partners (SITA, EADS CCR, Sogerma Services, and the Hautes-Pyrénées Prefecture) have built a dedicated dismantling facility at Tarbes airport in south-west France to undertake the project and plan for this facility to become a centre of excellence for commercial airframe dismantling. The partners plan to develop safe, environmentally aware efficient processes for the dismantling process.

There are several drivers behind the PAMELA project. Airbus estimates between 200 and 300 aircraft per year over 20 years will be taken out of service. Some of the first Airbus airplanes have already been retired from revenue service operations, and “there are increasing forecasts of the numbers of commercial aircraft that will be withdrawn from service in the coming decade,” according to Bruno Costes, Airbus’ Director of Environmental Affairs. The buoyant second hand aerospace parts market is seen as the beneficiary of the PAMELA project, and a key aim is to ensure that serviceable parts are returned to the market while out-dated and unserviceable parts are correctly destroyed and removed from the market.

PAMELA will also feed information back to the European Commission where it is believed that ideas are being developed for the introduction of an aerospace end of life directive, similar to the automotive end of life directive.

9 AFRA (Aircraft Fleet Recycling Association)

AFRA comprises a voluntary group of individuals and companies that have agreed to work in a cooperative fashion to provide full aircraft product life cycle capability. This comprises:

- the recycling of manufacturing and maintenance scrap,
- storage of aircraft that are currently out-of-service
- refurbishment of aircraft that can go back into revenue service,
- disassembly,
- responsible parts management, and
- recycling of materials from aircraft that are no longer marketable.

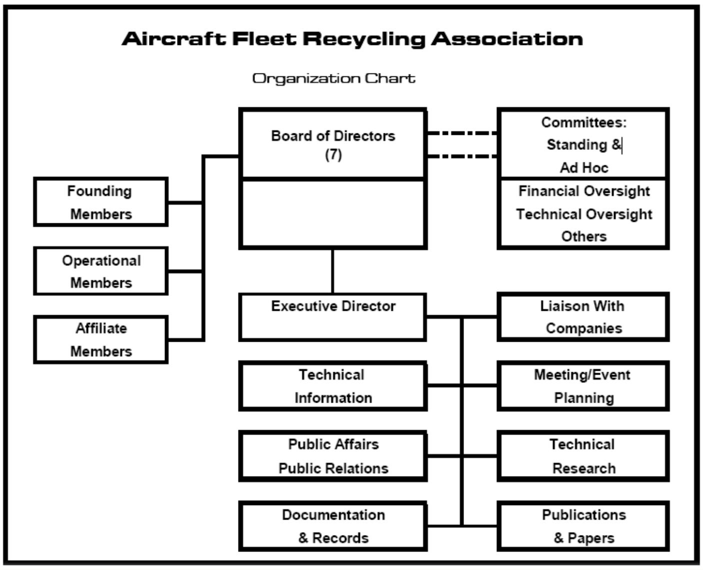


Figure 14. AFRA Organisation Chart

Application for membership of AFRA is open to all and applications are approved by the board of founding members.

AFRA's members agree to seek to define, document and disseminate the best practices and processes that will maximize the value of reclaimed material in terms of quality and quantity in the aerospace. Members agree to ensure that:

- aircraft and parts recovered from them are safe for future use in aerospace applications
- unserviceable parts and components are disposed of in a responsible manner
- best practice is spread across the AFRA membership and to all interested parties involved in the storage, maintenance and disposal of aircraft irrespective of the manufacturer of that aircraft
- at disassembly the airframe and its components are disposed of in accordance with current legislation and best environmental practice.

An aim of AFRA is to work with legislators to show that the aerospace sector is behaving responsibly when it comes to aerospace end of life issues and so to reduce the likelihood of imposed legislation. AFRA is managed via a Board of Directors taken from the founding members, one of which also provides the Executive Director. An AFRA organisation chart is shown in Figure 14, and current members include Boeing, Evergreen Air Center, Bartin Recycling, Chateauroux Air Center, Air Salvage International, Faraday Advance, Europe Aviantion, Milled Carbon, Oxford University Begbroke Science Park, WINGNet, Adherent Technologies, Rolls-Royce, The Memphis Group, Southern California Aviation, HKS Metals, Volvo Aero, Universal Recycling Company, Magellan Group, Huron Valley Fritz West, Aircraft End-of-Life Solutions and Aviation Suppliers Association.

A further 20 companies are in membership discussions.

Following the successful setting up of AFRA in 2006 and the identification of AFRA centres in the USA and Europe, AFRA plans to deliver and disseminate best practice in aircraft maintenance and disposal at these centres in 2007. Similar centres will then be established in the Far East, Australasia and South America.

10 Concluding Remarks

The airframe end of life sector is currently a relatively obscure but vibrant part of the aerospace materials supply chain. This relative obscurity is set to change given:

1. the increase in activity of airframe manufacturers in the self-regulation of disposal;
2. the increased awareness of product stewardship and associated part control issues by OEMs;
3. the increase in the inherent value of end of life airframes because of new technologies used in their manufacture and disposal; and
4. as the aerospace sector redoubles its efforts to make its use of materials more sustainable in the broadest sense.

Airframe manufacturers have already taken the initiative to learn more about the end of life sector and to ensure that best practise is developed and disseminated.

The UK possesses potentially important end of life technology companies and expertise that could increase end of life airframe value by making materials separation, recycling and reuse more economically viable. It is vital that these companies are linked to the global aerospace materials supply chain. End of life challenges in all industrial and product sectors can provide substantial business opportunities for UK companies and play a valuable part in realising the sustainable use of materials because of improved underpinning economic viability. Government, funding agencies, various technology transfer intermediaries and regional organisations must support the building of the UK end of life supply chain, including banks, leasing companies, salvage companies, recyclers, materials designers, universities and SMEs with niche technologies, parts re-sellers, etc., and to ensure that this UK infrastructure and know-how is connected to the wider global aerospace industry.

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