

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Passenger Aircraft at End-of-Life

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DGLR, RAeS, VDI, ZAL, HAW Hamburg

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Passenger Aircraft at End-of-Life

Abstract

Purpose – The presentation summarizes the state-of-the-art in aircraft end-of-life strategies.

Methodology – A literature review is the basic research method utilized. A visit to a dismantling site complemented the findings. Journeys and the Internet show examples of special reuse approaches giving aircraft and components a second life.

Findings – In the past aircraft went to "boneyards" at their end-of-life where they were simply left on their own. This should be avoided in the future. Instead aircraft are initially parked and stored. If no further operation is possible, aircraft are dismantled. Components and material is recycled as far as possible. The rest is disposed. Research has been done on the topic by Airbus, Boeing, other industrial companies, and academic institutions. The aircraft recycling industry starts to build up now by the launch of several recycling plants. The aircraft recycling market will slowly mature with associations like the Aircraft Fleet Recycling Association (AFRA) and with the publication of guidance material for best practices. The significant higher percentage of composites in modern aircraft types is a challenge for aircraft recycling. Special reuse approaches are only a niche market and not able to cope with the number of aircraft that need to be decommissioned each year.

Value – The presentation gives a year 2022 overview on the state-of-the-art of aircraft end-of-life handling with many pictures.



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 <http://www.AeroLectures.de>

Motivation

- About **1,000 commercial aircraft** reach the end of their lives **every year**.
- The **safe, responsible** and at the same time **economical recycling** of these machines is a major challenge.
- This must be considered when **designing new aircraft**.
- However, the **composite materials** that **are** increasingly being used are **a recycling problem**.
- A **new aircraft dismantling industry** is emerging.
- Much is developed in the **recycling processes**.

Passenger Aircraft at End-of-Life

This lecture is based on:

- **Project : HAW Hamburg, Aeronautical Engineering Studies**

MAASS, Svenja, 2020. *Aircraft Recycling – A Literature Review*. Project. Hamburg University of Applied Sciences, Aircraft Design and Systems Group (AERO). Available from: <https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2020-04-05.018>.

- **HAW-Bericht: Verkehrsflugzeuge am Lebensende**

SCHOLZ, Dieter, 2022. *Verkehrsflugzeuge am Lebensende*. Bericht. Hochschule für Angewandte Wissenschaften Hamburg, Aircraft Design and Systems Group (AERO). Verfügbar unter: <https://doi.org/10.48441/4427.359>. Direkt zum PDF: <https://purl.org/aero/RR2022-03-10>.

- **Artikel in Airliners.de, die Wissensplattform für die deutsche Luftverkehrswirtschaft**

SCHOLZ, Dieter, 2022-02-25. Der Produktlebenszyklus eines Flugzeugs endet nicht mit der Ausflottung. In: *airliners.de*. Archiviert als: <https://perma.cc/5AUE-42VN>.

- **Online News der HAW Hamburg**

SCHOLZ, Dieter, 2022-03-10. *Verkehrsflugzeuge am Lebensende*. Online News. Hochschule für Angewandte Wissenschaften Hamburg, Department Fahrzeugtechnik und Flugzeugbau. URL: <https://www.haw-hamburg.de/detail/news/news/show/verkehrsflugzeuge-am-lebensende>, <https://perma.cc/65E2-4NDR>.



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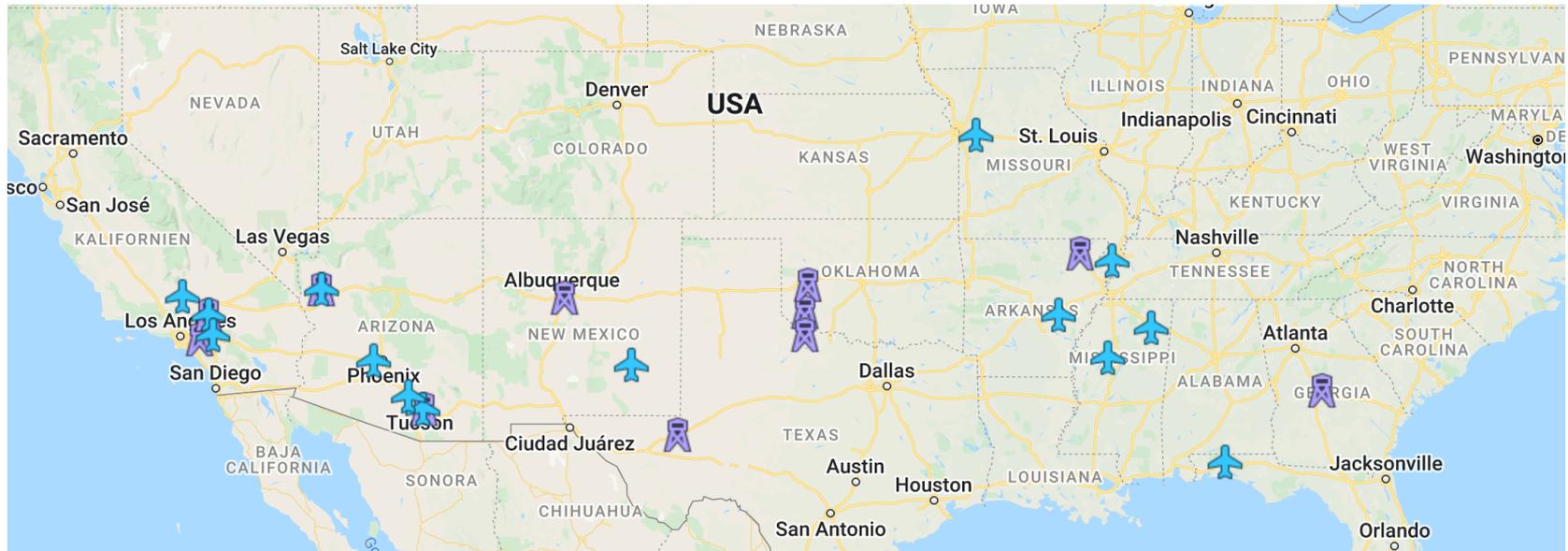
- **Aircraft Boneyards**
- **Recycling**
- **End-of-Life**
- **Airbus and Boeing Activities**
- **Composite Materials**
- **Special Reuse**
- **Summary**

Aircraft Boneyards

Aircraft Boneyards

- Boneyards in the USA

<https://AirplaneBoneyards.com>



Post-WWII military aircraft boneyards in the U.S.



Major commercial aircraft boneyards in the U.S.



Major commercial aircraft boneyards outside the U.S.

Aircraft Boneyards

- 309th AMARG, Tucson, Arizona, USA



<https://AirplaneBoneyards.com>



Aircraft Boneyards

- By far the largest site is 309th AMARG, Tucson, Arizona, USA.
Dedicated to military aircraft.
- These F-84 were decommissioned in the 1950th to AMARG. A photo from 1980.

Source: Wikipedia (in the public domain)



Aircraft Boneyards

- 309th AMARG, Tucson, Arizona, USA (1946)



<https://AirplaneBoneyards.com>

Aircraft Boneyards

- 309th AMARG, Tucson, Arizona, USA: B36 Peacemaker



<https://AirplaneBoneyards.com>

Aircraft Boneyards

- 309th AMARG, Tucson, Arizona, USA: B47 Stratojets



<https://AirplaneBoneyards.com>

Aircraft Boneyards

- 309th AMARG, Tucson, Arizona, USA: Boeing B29 Superfortress



<https://AirplaneBoneyards.com>

Aircraft Boneyards



- Kingman Airport, Arizona, USA

<https://AirplaneBoneyards.com>

Aircraft Boneyards

<http://www.aeroprints.com>



- Pinal Airpark, Arizona, USA



- Kingman Airport, Arizona, USA

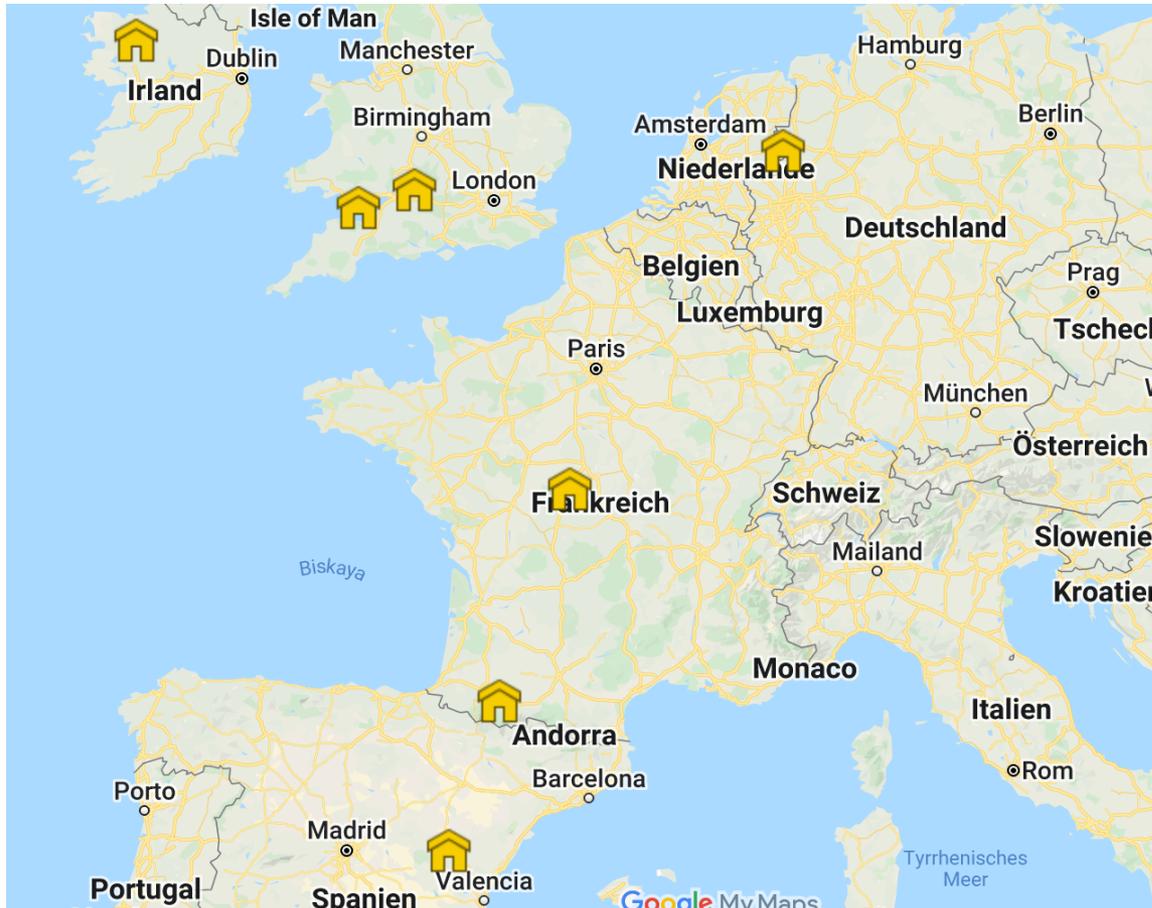
<https://AirplaneBoneyards.com>

Aircraft Boneyards



Major commercial aircraft boneyards outside the U.S.

- Boneyards in Europe



<https://AirplaneBoneyards.com>

Aircraft Boneyards

- Chateauroux, France: British Airways, A380

<https://AirplaneBoneyards.com>



- Bournemouth, UK: Planes from British Airways



Aircraft Boneyards

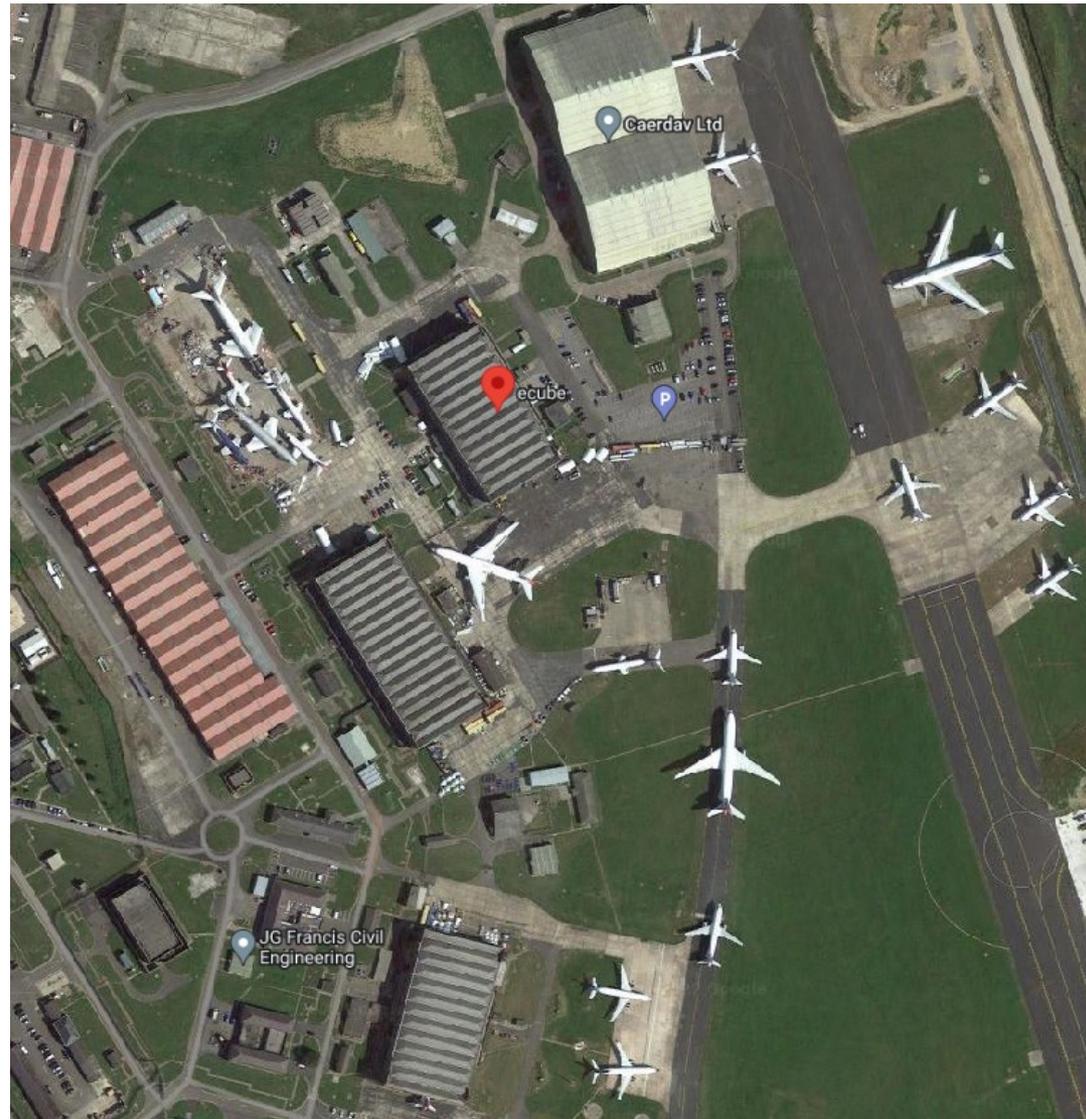
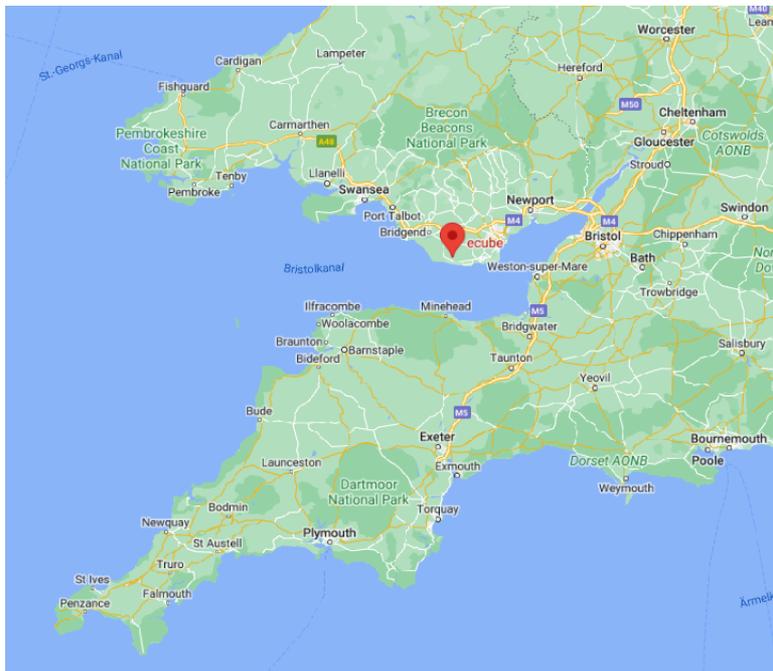
- Tarbes-Lourdes Pyreness Airport, France
- Tarmac Aerospace, Teruel Airport, Spain



<https://AirplaneBoneyards.com>

Aircraft Boneyards

- eCube Solutions, St. Athan, UK



Aircraft Boneyards



Major commercial aircraft boneyards outside the U.S.

- Boneyard in Australia



Alice Springs Airport

<https://AirplaneBoneyards.com>

Recycling

Aircraft End-of-Life: Parking => Storage => Dismantling

- Aircraft end-of-life has become increasingly important over the past two decades.
- It is no longer about **parking** the aircraft forever, but rather about a **temporary storage**, followed in the best case by the **restart** or **dismantling**.
- This procedure avoids the accumulation of more and more aircraft.
- The largest operation in Europe is located at **Teruel Airport in Spain**.
- **140 aircraft** can be accommodated at Teruel Airport.



Teruel Airport, Spain. Attaching foils to protect the cockpit windows for an aircraft to be stored. Source: <https://www.tarmacaerosave.aero>



Aircraft stored at Tarmac Aerosave. Source: <https://www.tarmacaerosave.aero>.

The Life Cycle of an Aircraft

- The **life cycle of an aircraft** can be divided into basic phases:
 - development,
 - production,
 - operations/maintenance and
 - end of life.
- The life cycle can be analyzed with a **life cycle assessment (LCA)** according to ISO 14040 and ISO 14044.
- The method was **extended for use in aircraft** (dissertation, Johanning, HAW Hamburg¹).
- **Flight operations dominate with more than 99% over the entire life cycle.**
- This is because flight operations take place every day, but production and end-of-life processes only occur once in an aircraft's lifetime.

¹ Johanning, Andreas, 2017. *Methodik zur Ökobilanzierung im Flugzeugvorentwurf*. München, Verlag Dr. Hut. Dissertation. Download: <http://Airport2030.ProfScholz.de>

The Life Cycle of an Aircraft

- This presentation is about the **end of life** of aircraft – and thus actually about a **tiny part of the environmental impact** of aircraft.
- Nonetheless, the **task** at hand is **gigantic**:
 - Over the next 30 years,
 - 29000 passenger planes will reach their end-of-life,
 - no matter how civil aviation continues to grow. That's about **1000 planes a year**.

Tasks at End-of-Life

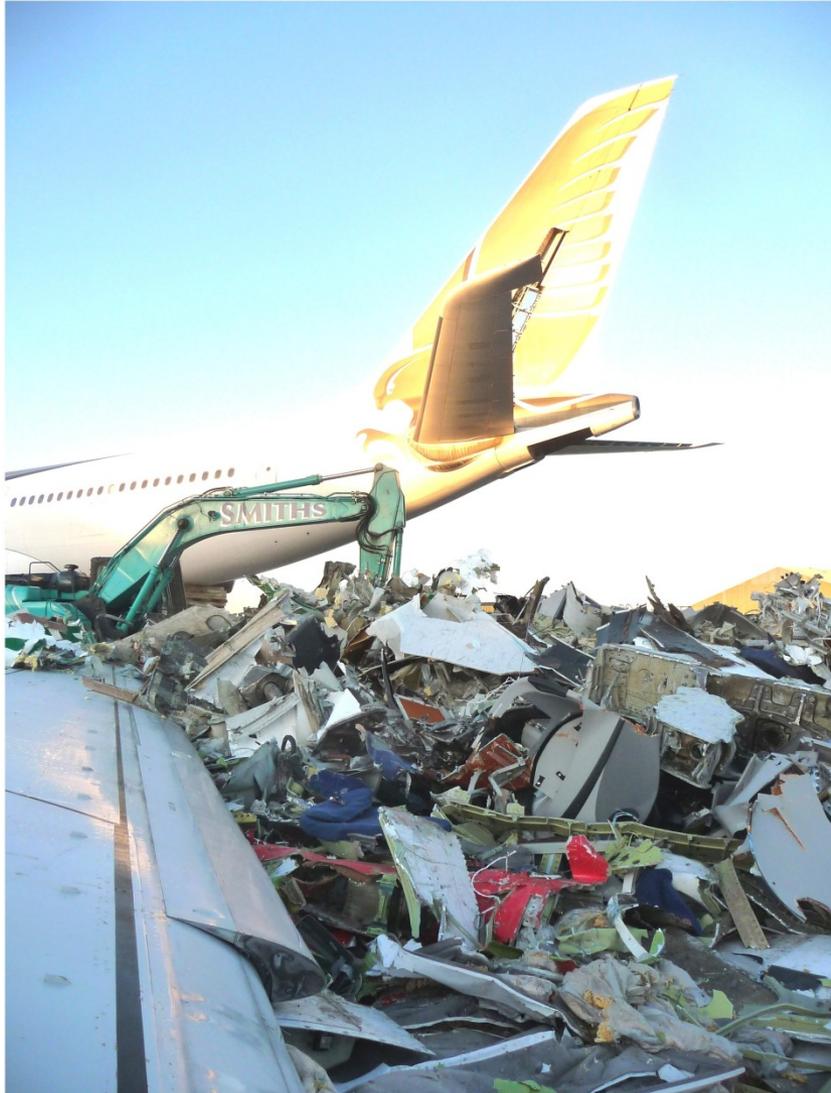
- These **tasks** are pending at the end-of-life:
 - **decommissioning**, careful **disassembly**, and violent **dismantling**.
- After the aircraft has been dismantled, a distinction is made between **reuse (recycling)** or **disposal (disposal)** depending on the component or material.
- For economic and ecological reasons, we aim to achieve **as high a percentage of reuse as possible (recycling rate)**.
- But what cannot be reused must be **disposed** of:
 - landfill or incineration (burning).
- When it comes to **recycling**, a distinction is made between
 - the use of secondary components and secondary raw materials.
- Accordingly, a distinction can also be made between
 - **component recycling rate** and a **material recycling rate**.
 - Aircraft achieve a recycling rate (based on mass) of 60% ... 85%, with more being sought.



Disassembly of an aircraft at Tarmac Aerosave. Source: Airbus, <https://perma.cc/SZS7-CDBX>.



Cutting a wing at Tarmac Aerosave. Source: <https://www.tarmac aerosave.aero>.



When an aircraft is dismantled by force, a voluminous heap of scrap is initially created. The parts are shredded, separated according to their density and fed into further recycling processes. What is left is disposed in a landfill.

eCube Solutions, St. Athan, UK



eCube Solutions, St. Athan, UK

Recycled Components

- In the case of aircraft, the recycling of components is of great economic importance.
- Aircraft components are expensive, so used parts can still fetch high prices.
- Certain components on the aircraft are designated as Life-Limited Parts.
- These components have a lifespan described in flight hours, cycles, or calendar time.
- Proper technical documentation is part of airworthiness and must allow back-to-birth traceability.
- The documentation must always show the life status in flight hours, cycles or calendar time.
- For used parts from recycling, the functionality results from the fact that they were operated correctly on the last flight or from a quality check.
- Recycled components can be
 - sold with their current life status, or
 - sold as new after appropriate maintenance.

Recycled Components

Aircraft parts are removed, labeled, checked for quality, serviced if necessary and packaged for sale.



eCube Solutions, St. Athan, UK

End-of-Life

End-of-Life Does Not Necessarily Have Anything to Do with Age

- **End-of-life** does not necessarily have anything to do with **age** or overall **use** of the aircraft.
- Irrespective of flight hours and flight cycles, an **aircraft becomes obsolete if its operating costs are too high** compared to other aircraft, or if there is simply no demand for flights.
- Under favorable circumstances, passenger **aircraft can be operated economically for around 30 years**.
- However, the end of an aircraft's life is always determined by an **economic consideration**.
- **End-of-life can occur after as little as 13 years**, as was recently the case for some Airbus A380 aircraft.
- If there is no buyer for the used aircraft, then the only choice left is between further **operation** or **scrapping**.
- You try to sell the aircraft in individual parts. The **engines are the most valuable**.
- **Cargo aircraft** have lower usage than passenger aircraft and do not require regular expensive cabin renewal and **can therefore be kept in service longer**.



Among the early A380s due to be dismantled is this ex-Singapore Airlines aircraft. It only lived to be 13 years old.

Source: Flight Global (2021-11-09)

The End-of-Life often Begins Slowly

- An **aircraft** that has no place on the market today can **possibly be used again later**.
- This is due to fluctuations in supply and demand and changing opportunities to make profits.
- An operator will therefore be willing to **leave the aircraft idle at low running costs** for the ability to **reactivate the aircraft if necessary**.
- A distinction can be made between **parking** and **storage**.

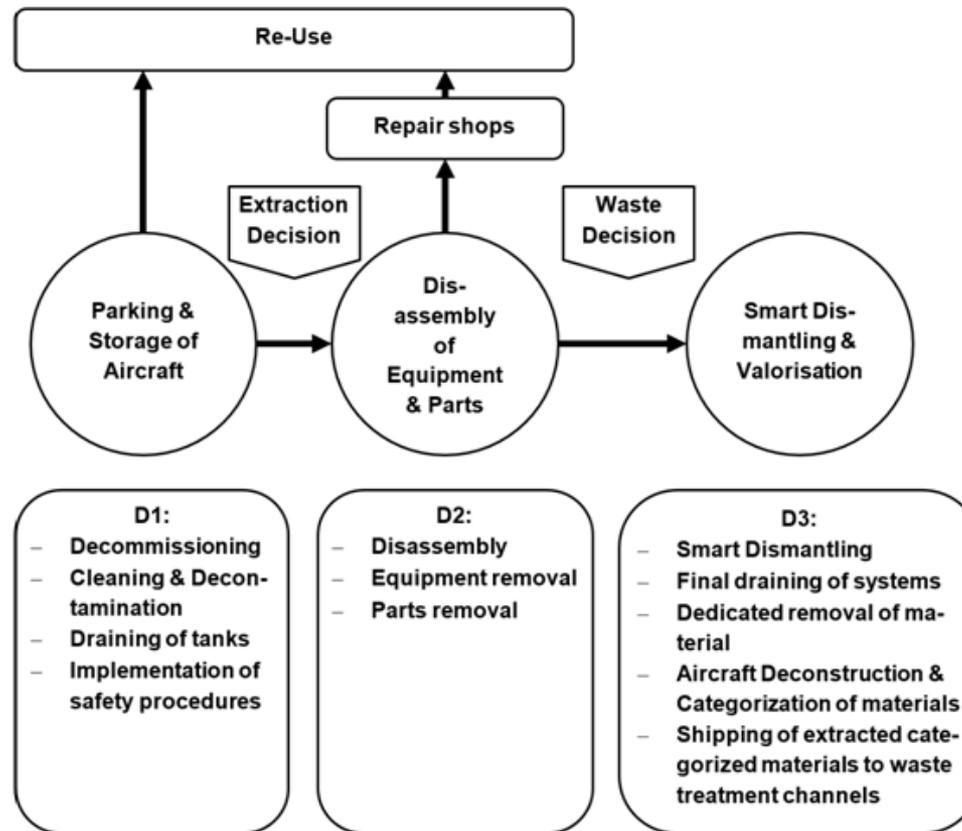
Airbus and Boeing Activities

Airbus and Boeing Started Research and Recycling Facilities

- The two major civil aircraft manufacturers, Airbus and Boeing, both independently started **research projects** and recycling **test facilities**.
- Both manufacturers are benefiting from the results of their efforts by being able to incorporate the learnings into the **development of their next-generation aircraft**.

Airbus started the PAMELA Project

- Airbus started the **PAMELA** (**P**rocess for **A**dvanced **M**anagement of **E**nd-of-Life of **A**ircraft) project in 2005 in collaboration with
 - Suez-Sita - a French recycling company - and
 - the LIFE working group (l'Instrument Financier pour l'Environnement).
- In early 2006, an **Airbus A300-B2 was completely dismantled** and dismantled at **Tarbes Airport**.
- in **2006**, it was the world's **first demonstration of a complete dismantling** of a passenger aircraft.



The so-called **3D approach** to aircraft dismantling from the **PAMELA** project

Adopted from:

RIBEIRO, Júnior S., DE OLIVEIRA GOMES, Jefferson, 2015. Proposed Framework for End-of-life Aircraft Recycling. In: *Procedia CIRP*, vol. 26, pp. 311-316. Available from: <https://doi.org/10.1016/j.procir.2014.07.048>

Airbus Founded Tarmac Aerosave

- After the PAMELA project, Airbus, together with other companies, founded the **Tarbes Advanced Recycling and Maintenance Aircraft Company (Tarmac Aerosave)**.
- A new plant opened in **Teruel, Spain** in 2013, followed by **Toulouse Francazal, France** in 2017.
- In 2020, **Tarmac Aerosave has recycled a total of 170 aircraft** since inception.
- In addition to **Airbus**, the two **shareholders of Tarmac Aerosave** are today
 - the **Safran** Group and
 - **Suez**.
- Around the same time, many other similar companies emerged in Europe.

Boeing Founded the Aircraft Fleet Recycling Association (AFRA)

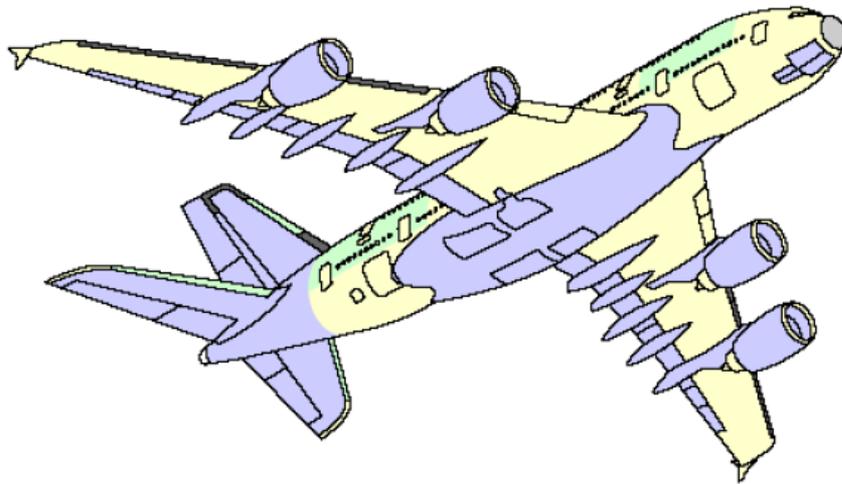
- In April 2006, **Boeing** founded the **Aircraft Fleet Recycling Association (AFRA)** in partnership with ten European and American companies.
- The founding members come from sectors such as **waste management**, raw **material production**, aircraft **maintenance** and manufacture, parts **suppliers** and service providers.
- They are committed to using their combined know-how, including aircraft scrapping, at the **highest technical level**.
- AFRA is a self-financing non-profit organization whose members work under a certificate with defined processes.
- With the collective experience of AFRA members, a guide to **"Best Management Practice for Management of Used Aircraft Parts and Assemblies and for Recycling of Aircraft Materials" (BMP)** was developed.
- For members or companies applying for **membership**, the **BMP document** sets out the verifiable **standards**.

Composite Materials

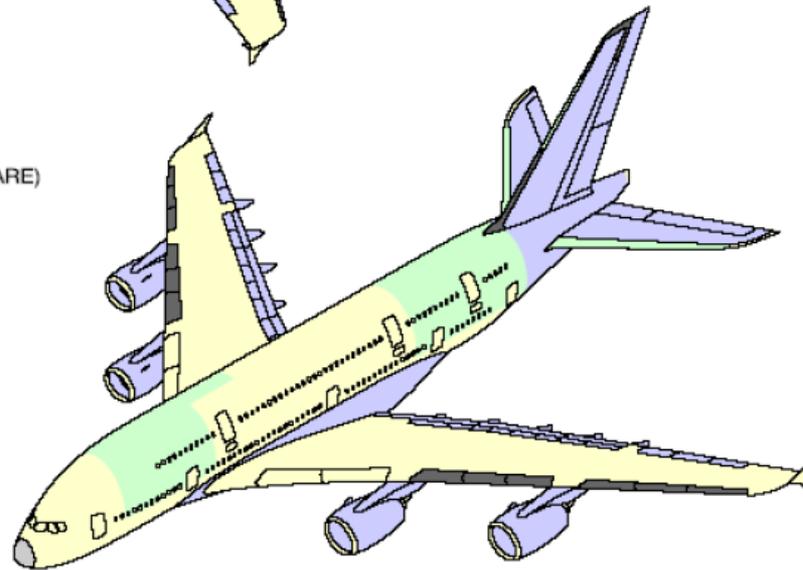
Challenge: The Increasing use of Composite Materials

- A particular challenge is the increasing use of composite materials for which there are still **no mature recycling processes**.
- In 1970, the Boeing 747 still managed almost entirely without composite materials.
- Since then, the proportion of **composites** has increased with each new aircraft type, reaching **50% with the Boeing 787 and Airbus A350**.

COMPOSITE MATERIALS



- Carbon Fiber Reinforced Plastic (CFRP)
- Glass Fiber Reinforced Plastic (GFRP)
- Quartz Fiber Reinforced Plastic (QFRP)
- Glass Reinforced Aluminum Laminate (GLARE)



Airbus,
<https://perma.cc/9PXR-DDMF>

Compound Waste Can Be Processed in Three Ways

- Carbon fiber and epoxy are most commonly used in large commercial aircraft.
- The composite parts from the aircraft will only be produced in large quantities in 25 years.
- This means the problem is still ahead of us.
- The compound waste can be processed
 - mechanically,
 - thermally or
 - chemically.

Processing Composite: **Thermally**

- Thermal processes use **high temperatures**.
- First, the parts are **mechanically broken** down into manageable pieces, which are then fed into a fluidized bed reactor.
- The **hot air** flow **decomposes** the matrix.
- The clean fibers are then separated from the air by a **cyclone**:
 - Heavier **components** such as metallic components are not carried up with the airflow and are therefore **separated**.
 - The **resin** from the matrix is completely **oxidized** in an afterburner that produces energy.
- The resulting **fibers** have a **fluffy** shape and a length of up to 10 mm.
- So far, it has not been possible to prevent a **reduction in tensile strength**, but the modulus of elasticity and the surface quality of the recycled fibers are comparable to fresh fibres.
- The recycled fibers can only be **used in non-oriented fabrics**.

Special Reuse

Special Reuse Approaches

- In contrast to these common disposal strategies, there are **special reuse approaches**.
- The general idea is to **give an aircraft component a second life** outside of aviation.
To be distinguished:
 - **raw parts** for collectors or used for similar purpose (pump, electric motor, seat),
 - **art work** from aircraft parts (wall decoration, sculpture),
 - polished and extended **parts for a new purpose** (chair, table, lamp, clock).
- **Aircraft** or **fuselages** with new or intact cabin interiors used as:
 - **apartment (home)**,
 - **hotel, café**,
 - **registry office**,
 - eye-catcher, **monument** or aircraft in a museum.
- Note: **This** is only a **niche market** and **not able to cope with the volume** of material to be handled when 1000 aircraft have to be decommissioned each year.

Airplane Raw Parts



<https://planereclaimers.aero/product/airbus-cockpit-panels-a318319320321330340>



<https://planereclaimers.aero/product/aircraft-remove-before-flight-ribbon-3>



<https://www.etsy.com/de/listing/1189498823>

Airplane Parts for New Purpose



Table
<https://www.etsy.com/de/listing/897207377>



Bar from fuselage structure
<https://www.etsy.com/de/listing/877297683>



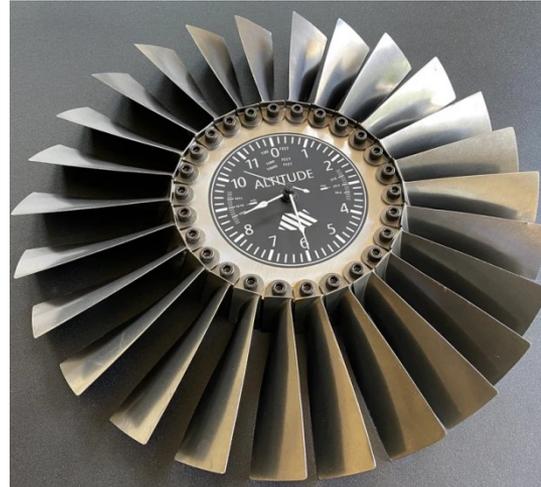
Clock from window

<https://www.etsy.com/de/listing/714347807>



<https://www.etsy.com/listing/903331577>

<https://www.etsy.com/de/listing/980810739>



Wall clock from turbine disk

<https://www.etsy.com/de/listing/622147065>



Wall illumination (LED)
from slat



Table from slat

<https://www.etsy.com/de/listing/897207377>



Illumination hanging from the ceiling based
on aircraft structure

<https://www.etsy.com/de/listing/897207377>

Airplane Art Work



Painted A320 pylon fairing
<https://planereclaimers.aero/product/jim-vision-painted-a320-r-h-pylon-fairing>



View from back



Airbus A319 brushed aluminum window
<https://planereclaimers.aero/product/airbus-brushed-aluminium-window>

Aircraft or Fuselage as Home



DESTINATIONS FOOD & DRINK NEWS

Bangkok airplane graveyard becomes home for families

CNN Staff • Updated 16th September 2015



DESTINATIONS FOOD & DRINK NEWS

Bangkok airplane graveyard becomes home for families

CNN Staff • Updated 16th September 2015



<https://edition.cnn.com/travel/article/bangkok-plane-graveyard>





<https://planereclaimers.aero/2021/10/14/are-aircraft-pods-the-new-outdoor-craze>



<https://planereclaimers.aero/custom>



A **Boeing 727** is the **home** of Bruce Campbell in Oregon, USA, <http://airplanehome.com>
<https://www.loveproperty.com/gallerylist/85843/the-man-who-lives-in-a-boeing-727-in-oregon>



House extension with an Iljuschin IL-18 in Russia.
<https://englishrussia.com/2009/06/29/plane-in-the-house>



Home of Joe Axline is a **MD-80** and a **DC-9-41** at Sport Flyers Airport (27XS), Brookshire, Texas, USA
<https://www.newsweek.com/airplane-home-unusual-property-1652350>



<https://www.facebook.com/PlaneHome>

Aircraft as Hotel



The **hotel** offers also accomodation in a somewhat smaller "Cockpit Cabana" based on a **McDonnell Douglas MD-82**.

This suite at the **Hotel** Costa Verde on the coast of Costa Rican was once a **Boeing 727**. You can sleep with sea view next to tropical beaches in this "727 Fuselage Home". Puntarenas Province, Quepos, Costa Rica. <https://costaverde.com>

Source: <https://edition.cnn.com/travel/article/planes-retired-what-happens/index.html>, Vincent Castello (before 2018)

★★★★★
VLIEGTUIGSUITE



Hotel in IL-18: De Zanden 61b, 7395 Teuge (airport near Apeldoorn), The Netherlands, <https://www.vliegtuighotel.nl>



Hostel in a **Boeing 747**, JUMBO STAY,
Jumbovägen 4, Stockholm Arlanda
<https://www.jumbostay.com>





Projet Envergure
Artist's impression of planned **Airbus A380** hotel

<https://www.projet-envergure.com>

Aircraft as Restaurant, Café or Registry Office



Douglas DC-3 plane attached to the McDonald's **restaurant** in Taupo, New Zealand. Photo by Fuwuyuan, 2012, CC BY-SA
https://en.wikipedia.org/wiki/File:DC-3_of_McDonald_Taupo.jpg





Restaurant
 in a
Boeing KC-97
 1665 N.
 Newport Rd.
 Colorado Springs
 Colorado, USA



<http://www.theairplanerestaurant.com>



Flug-Café Neu Wulmstorf

Sie können ab morgen, Sonnabend, 21. Oktober 1967

64 Flugplätze buchen.

Machen Sie sich ein paar nette Flugstunden.

- **START** täglich ab 13 Uhr, sonnabends und sonntags ab 10 Uhr.
- **LANDUNG:** 1 Uhr.
Unsere Stewardessen servieren Ihnen gepflegte Getränke und Speisen.

Auf Ihren Besuch freuen sich
Flugkapitän Siegfried Karas u. Frau



Fotos: Archiv Gemeinde Neu Wulmstorf

Airplane café in a Lufthansa Lockheed Super Constellation. Details next page.

A Heavenly Delight – Airplane Café in a Lufthansa Lockheed Superconstellation

From 1967 to 1975 one of the most bizarre cafés in the world was in Neu Wulmstorf near Hamburg, Germany. In addition to the mini golf course, opposite the outdoor pool, you will find four tennis courts today. That wasn't always like that. Fifty years ago you would have had a 33 meter passenger plane found there with a wingspan of 44 meters - a discarded Lufthansa Superconstellation D-ALOP at the age of 12 and with 26715 flight hours. Butcher Siegfried Karas, then chairman of the mini golf club, bought it for 23000 DM (11500 EUR), transported it to Neu Wulmstorf and converted it into a cafe. He invested a total of 75000 DM (37500 EUR) before opening his curious restaurant called "Flugcafé" (flight café). The transport should have swallowed a good chunk of the money. The aircraft was transported from Hamburg airport to the harbor, from there on a pontoon across the river Elbe to Hamburg-Harburg and then to Neu Wulmstorf again by truck via the country road B73. Finally, two 45-ton cranes assembled the giant bird on site. Three stewardesses served for the first time on October 21, 1967 hot and cold meals, cakes, pastries and international drinks in three rooms (a bar, a restaurant and a club room). For many this was the attraction of the region, for others an eyesore and cause for complaint. As spectacular as the story begins, its end is unfortunately terribly unglamorous. After the first good years, the airplane cafe was no longer an attraction, the guests stayed away, the business barely made a profit. A rescue attempt by an interest group for the preservation of old commercial aircraft failed after the closure of the cafe in 1975. The deceased owner's widow had to vacate the place. An investor was found who left the same year with the good old super bird. Here the story ends for the village New Wulmstorf.

Translated from:

Hier – Das Magazin für Neu Wulmstorf, 2017, No 1, Kanebley Consulting GmbH, Im Dorfe 4, 21629 Neu Wulmstorf, Germany. Journal discontinued.



Standesamt (registry office) Rhinow in an Iljuschin IL-62

Am Gollenberg 10, 14728 Gollenberg, Germany

On October 23, 1989, captain Heinz-Dieter Kallbach managed the spectacular landing of the four-engine long-haul Interflug aircraft of type Iljushin 62 on the only 860 m short glider airfield in Stölln. Otto Lilienthal carried out his pioneering flight tests on this site from 1893 to 1896.

<https://hochzeits-location.info/hochzeitslocation/flugzeug-il-62-lady-agnes-otto-lilienthal-verein-stolln>

Aircraft as Monument



A **Tupulev TU-134** as a **monument** in front of Chişinău International Airport. Chişinău, is the capital of the Republic of Moldova. On September 13, 1990, a TU-134 made the first flight on the international route Chisinau-Frankfurt.

Aircraft in a Museum



A **Tupulev TU-144** in "Technikmuseum Sinshheim", Germany. In the foreground a **Vickers Viscount**. Right: The TU-144 followed by the **Aérospatiale-BAC Concorde**. Below: **Suchoi T-4**, designed for Mach 3. On display at Central Air Force Museum in Monino near Moscow, Russia.

Summary

Passenger Aircraft at End-of-Life

Summary (1 of 2)

- Aircraft Boneyards
 - USA
 - Europe
 - Australia

- Recycling
 - Aircraft End-of-Life: Dismantling
 - The Life Cycle of an Aircraft
 - Tasks at End-of-Life
 - Recycled Components

- End-of-Life
 - End-of-Life Does Not Necessarily Have Anything to Do with Age
 - The End-of-Life often Begins Slowly

Passenger Aircraft at End-of-Life

Summary (2 of 2)

- Airbus and Boeing Activities
 - Airbus and Boeing Started Research and Recycling Facilities
 - Airbus started the PAMELA Project
 - Airbus Founded Tarmac Aerosave
 - Boeing Founded the Aircraft Fleet Recycling Association (AFRA)

- Composite Materials
 - Challenge: The Increasing use of Composite Materials
 - Compound Waste Can Be Processed in Three Ways
 - Processing Composite: Thermally

- Special Reuse
 - Home
 - Hotel / Hostel
 - Café
 - Registry Office
 - Monument or on display in a museum

Passenger Aircraft at End-of-Life

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