

A Call to Action:

# “Applying Circular Economy Principles to Aircraft”



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## ***ECATS Working Group: Circa — Circular Aviation***

Circa is a volunteer working group within ECATS dedicated to accelerating circular aviation through research, collaboration, and policy dialogue.

### **KEY TAKEAWAYS**

- ▶ Aviation's embodied carbon and material waste are under-addressed — circular economy must become a strategic priority alongside propulsion innovation.
- ▶ An estimated 600–1,000 aircraft are decommissioned annually; this will reach ~1,200 by 2030, yet no globally standardised End-of-Life framework exists.
- ▶ ISO 59004/59020 standards now provide a solid circular economy baseline, but aviation-specific adaptation and regulatory embedding remain absent.
- ▶ No single methodology currently captures the full systemic character of circularity — LCA alone is insufficient; combined with MCI and economic indicators it is more robust.
- ▶ Composite materials are increasingly difficult to recycle; material selection must balance performance with end-of-life recovery from the design stage.
- ▶ Circular business models (leasing, remanufacturing) exist in aviation but are limited; the MRO and EoL supply chain remains a critical knowledge gap.
- ▶ Policy frameworks — from the European Green Deal to ICAO — inconsistently address circular aviation; coordinated regulatory action is urgently needed.
- ▶ Digital Product Passports (DPPs) and extended Bills of Materials (BoMs) are key enablers for transparency and circular practices throughout the aircraft lifecycle.

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## Introduction to Circular Economy in Aviation

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The aviation sector accounts for 2.5% of global CO<sub>2</sub> emissions, comprising over 30,000 active aircraft.

Chester and Horvath<sup>2</sup> demonstrated that the embodied CO<sub>2</sub> of aircraft during manufacturing makes up ~6% of their lifetime emissions. There is a clear need to address the material component of aviation's environmental impact and embrace circular economy principles to reduce the dependency on virgin materials, extend the lifespan of components, and minimise waste. The European Green Deal and the current geo-political situation indicate a circular economy and its strategies as a possible solution for a resilient European aviation sector.

This context requires aviation to undergo a paradigm shift; aviation must embed sustainability in the core of its modus operandi. This will redefine aircraft design and operations across its entire life cycle. Aviation has begun to embrace the challenge of implementing new propulsion solutions and energy sources, exploring the impact on new aircraft designs. On the other hand, the life cycle character is less evident, in particular with regards to the End of Life (EoL) phase. EoL practices have not evolved at the same pace as other technologies and solutions for sustainable aviation.

A pressing need is developing within the aviation sector to adopt more sustainable EoL practices as an estimated 600 to 1,000 aircraft are decommissioned annually<sup>3</sup> with varying degrees of circularity being applied. It is predicted that the number of aircraft being decommissioned will reach 1,200 annually by 2030. Further, the material content of each aircraft is becoming increasingly difficult to recycle as the adoption of resin-based composites has become more prevalent. Rare earth materials, high value metals, and environmentally detrimental compounds are also present, reinforcing the need for better EoL processing for the significant volumes of aircraft currently in use.

To address these challenges, the network for an Environmentally Compatible Air Transport System (ECATS) established a working group: Circular Aviation (CircA)<sup>4</sup>. The group focusses on the research necessary towards achieving a circular economy in aviation (shortened as circular aviation); the particular focus of the group, and of this white paper, is on aircraft. This paper presents an overview of the circular economy in aircraft, covering the definition, assessment, enabling strategies, and policy aspects.

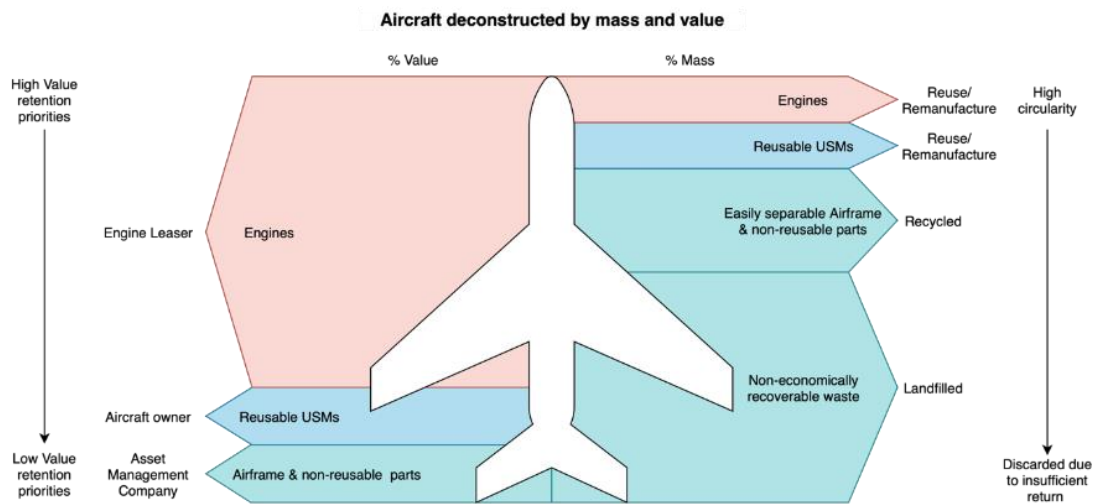


Figure 1. Breakdown of aircraft into constituent mass and value with end-of-life destinations and owners.

## Defining Circular Economy in Aviation

In academic and grey literature, numerous definitions of circular economy exist. Standardization initiatives have resulted in the release of five ISO standards<sup>5</sup>, shown in Table 1, with an additional one under development.

Table 1. Relevant ISO standards for circular economy.

Standard	Date	Title
ISO 59004	2024	Circular economy — Vocabulary, principles and guidance for implementation
ISO 59020	2024	Circular economy — Measuring and assessing circularity performance
ISO 59010	2024	Circular economy — Guidance on the transition of business models and value networks
ISO 59040	2025	Circular economy — Product circularity data sheet
ISO/TR 59032	2024	Circular economy — Review of existing value networks
ISO/DTR 59031	draft	Circular economy — Performance-based approach — Analysis of cases studies

These standards define circular economy as “an economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development”<sup>6</sup>. The ISO standards clarify the difference between “circular economy” and “circularity”, two expressions commonly used synonymously; in ISO 59020:2024, circularity is defined as a measure of circular economy.

Before the introduction of the ISO standards, various R-strategy frameworks were used to describe circular economy practices, typically ranging from three (Reduce, Reuse, Recycle)<sup>7,8</sup> to nine, as

seen in the European Taxonomy<sup>9</sup>. The ISO standards expand previous frameworks, harmonise circular economy principles and terminology, and provide guidelines and actions.

The current ISO standards are, however, not specific to aviation. Throughout the years, the aviation industry has developed several Best Industry Practices for Aircraft Decommissioning (BIPAD) such as the document issued by IATA<sup>10</sup> and the Aircraft Fleet Recycling Association (AFRA)<sup>11</sup>. These documents focus on the EoL phase, but do not include all aspects of circular economy. One attempt to create terminology for circular economy in the aviation sector based on the ISO standards has been recently published<sup>12</sup>.

Circular economy is also the backbone for the Ecodesign for Sustainable Products Regulation (ESPR)<sup>13</sup>. Ecodesign is standardised in ISO 14006:2020<sup>14</sup>. Its aim is to anticipate and minimise negative environmental impacts over a service or product lifecycle. In aviation, ecodesign is intertwined with the “Eco-Design TA” activities performed in Clean Sky and Clean Sky 2<sup>15</sup> programmes, which linked ecodesign with the REACH directive and hazardous materials. While rejecting hazardous materials is part of ecodesign, it is not the sole focus. The ESPR’s objectives align with the working group CircA, going beyond the focus on recycling and hazardous materials.

## Assessing Circular Economy in Aircraft

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Having defined the circular economy, tools and methodologies to monitor adherence and progress towards it are a necessity. Various methodologies have been proposed and are currently used to assess circularity, including circularity performance, the Material Circularity Index (MCI)<sup>18</sup>, Life Cycle Assessment (LCA), and material flow analysis.

LCA, standardized in ISO 14040<sup>16</sup> and 14044<sup>17</sup>, provides a framework for assessing the environmental impacts of products or services throughout their entire life cycle. It considers various environmental aspects, including energy and resource consumption, emissions, waste generation, and potential impacts on human health and ecosystems.

Despite the variety of tools, research has shown that no methodology is currently able to capture the systemic character of the circular economy. The evaluation of different environmental impacts and material flows for the entire life cycle of a product are essential contributions to the assessment of circularity. On the other hand, MCI does not include economic or social aspects; it must be combined with other assessments, as expressed also by the ISO standards.

In conclusion, there is currently no agreed circularity performance assessment; in aviation, circularity is primarily assessed via LCA<sup>19</sup>. This indicates a research gap that CircA wants to address.

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## Enabling Circular Economy

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In order to apply circular economy principles, several strategies can be considered at various stages of product development and product life cycle. ‘Design for disassembly’ or ‘modular design’ are frequently mentioned in aviation literature. Of relevance to enable circular strategies in aviation are material selection, business model, and Digital Product Passports (DPPs), which promote transparency by collecting and sharing data about a product’s lifecycle.

### Material Selection for Circular Aircraft

Aircraft materials have traditionally been selected for performance — mainly strength-to-weight ratio — without factoring in their environmental impact after use. Integrating circular economy strategies can meet multiple targets: not only lower environmental burdens, but also conserve resources, recover more value from materials at EoL, and reduce other impacts of aviation.

One pillar of a circular economy is the use of renewable or recyclable materials. Results of previous projects (e.g. PAMELA<sup>22</sup>) provide indications that up to 92% of aircraft weight can be recycled or reused. More recent work by eCube<sup>23</sup> is in the same range, and TARMAC Aerosave and ATR announced an 85.5% result for three aircraft<sup>24</sup>. This percentage varies by model and material use; without an agreed methodology, the validity of the provided figures and the consistency of recycling rates can be questioned.

Aluminium is recyclable, but composite materials — despite improving fuel efficiency — are difficult to recycle. Although their use is justified through lower operational impacts (measured by LCA), this does not fully capture circularity. Thus, material selection should consider both performance and broader system-level sustainability.

### Business Model and Incentives

The aviation sector largely operates on a linear ownership model, with few circular exceptions — most notably engines, which often remain with the Original Equipment Manufacturer (OEM) and achieve near-total recovery through refurbishment, remanufacture, or recycling. Aircraft leasing also supports a circular economy. However, the long lifespan of aviation assets limits widespread adoption of circular business models, as it delays material recirculation and complicates implementation across the supply chain.

To consider the implementation of circular business models, a thorough mapping of the stakeholders and the complete supply chain is necessary. The current concern in terms of material and part availability within the sector is redirecting attention to the Maintenance, Repair and Overhaul (MRO) and EoL supply chain. There is a clear research and knowledge gap in this area.

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## Current Status of Policy and Regulations

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Lastly, the lack of incentives and regulations in the aviation sector to enable circular practices must be mentioned. Despite the many general regulations concerning EoL, the aviation sector is regularly excluded; specific regulations (e.g. from EASA) are currently not binding. Incentives also do not address aviation specifically. Linking financing to sustainability targets has proven successful in other sectors.

Following the European Green Deal in 2019, circular economy strategies have been embedded in several European and national legislations. In the first Strategic Research and Innovation Agenda (SRIA) of the Clean Aviation Joint Undertaking, there was no mention of the circular economy; in the late 2024 update<sup>27</sup>, circular economy is mentioned as delivering social impact in relation to ecodesign — an incredibly narrow understanding of its value for aviation. ACARE’s Fly the Green Deal vision openly mirrors the objectives of the European Green Deal. As such, the goal of achieving climate neutral aviation by 2050 is linked to “the circular economy concept [...] being an equitable contributor”<sup>28</sup>.

Destination 2050<sup>29</sup> barely mentions circular economy, indicating the need to incentivize it as one regulatory action supporting innovation; the same applies to the newly released ARIS strategy<sup>30</sup>. Outside Europe, the concept of a circular economy is scarcely addressed. ICAO referenced it in their 2019 Environmental Report<sup>31</sup>, omitted it in 2022<sup>32</sup>, and it reappears in the latest 2025 report<sup>33</sup>. These global inconsistencies also hinder the adoption of circular technologies, as they are perceived as threats to competitiveness.

To monitor progress, initiatives are flourishing regarding standardisation of circularity performance, LCA, and other methodologies. Isolated initiatives towards guidelines for LCA for aviation are known from EREA, IAEG<sup>34</sup>, and from several industrial aviation companies and various European funded projects. Alignment of all those initiatives, under the coordination of EASA, is essential to ensure the uptake of LCA in aviation, in the form of Product Environmental Footprint Category Rules (PEFCR) for aircraft. Similar to a PEFCR for aircraft, standardisation of circular economy concepts and assessment, beyond the ISO standards, will be essential in the future.

## Conclusion and Recommendations

ECATS supports the correct integration of circular economy and its strategies in relevant SRIAs of the aviation sector, in line with European policies. Below are the key recommendations of the CircA working group:

### ECATS CircA RECOMMENDATIONS

- ✓ Extend the Bill of Materials (BoM) to include information regarding possible EoL strategies — establishing a bill of waste to enable correct disposal of waste resulting from aircraft dismantling.
- ✓ Adopt Digital Product Passports (DPPs) to support correct EoL strategies by including information on materials used throughout the aircraft's lifecycle.
- ✓ Develop a standardised EoL Bill of Practices for aircraft materials, in connection with other EoL practices.
- ✓ Support the uptake and improvement of existing guidance documents by the aviation regulatory authorities to create a global standard for EoL aircraft.
- ✓ Openly include aviation and aviation assets and products in ESPR future regulations to enable circular practices to be embedded in the European aviation industry.
- ✓ Incentivise dismantlers for material and value recovery, recognising the economic and environmental role of the EoL supply chain.

## List of Acronyms

Acronym	Meaning
AFRA	Aircraft Fleet Recycling Association
BIPAD	Best Industry Practices for Aircraft Decommissioning
BoM	Bill of Materials
CircA	Circular Aviation
DPP	Digital Product Passport
ECATS	Environmentally Compatible Air Transport System
EoL	End of Life
ESPR	Ecodesign for Sustainable Products Regulation
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MCI	Material Circularity Index
MRO	Maintenance, Repair and Overhaul
OEM	Original Equipment Manufacturer
PEFCR	Product Environmental Footprint Category Rule
SRIA	Strategic Research and Innovation Agenda

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## ECATS International Association

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ECATS International Association started in 2005 as a Network of Excellence on Aviation and Environment of more than 100 researchers within the European Framework Research Programme. After 5 years of joint research and exploring closer collaboration, this ECATS Network of Excellence was transformed into ECATS International Association, officially registered per 2 November 2010 by [Royal Decree] of Belgium.

The objective of ECATS is to promote and support its Members' joint activities and interests in the field of aviation & environmental impact. Its higher-level aim is to help making aviation sustainable, by:-

- Building up, maintaining and extending scientific expertise;
- Further linking and integrating expertise in relevant thematic areas and to exploit the multi-disciplinary platform available in ECATS;
- Organising exchange of information in particular about experience and development of related research; e.g., on basis of workshops, conferences, reports and publications, education and training, and web-based information;
- Providing liaison between customers and experts to provide integrated and professional support;
- Fostering the technical, strategic and political debate, for instance to initiate research work where identified to be crucial.

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