CIRCULAR AVIATION

A RESEARCH PROGRAMME OF THE FUTURE SKY JOINT RESEARCH INITIATIVE

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SUMMARY

Future Sky Circular Aviation is the framework programme promoted by the Association of European Research Establishments in Aeronautics (EREA) to tackle the multitude of environmental challenges faced by aviation in its path to become fully sustainable. It is part of Future Sky, an ambitious EREA initiative intending to address the main issues challenging the EU leading position on aviation.

The societal demand for sustainable aviation requires the development of appropriate, efficient and consistent solutions to reduce the present (and future) level of emissions and waste and, more in general, to reduce the overall aviation environmental footprint, without impacting economic growth and limiting the movement of passengers and freight.

So far sustainability in aviation has mainly referred to reducing greenhouse gases emissions from operations; therefore, the focus of R&T activities has been mostly on solutions connected to propulsion and reduction of fuel consumption. Though essential, this approach covers only part of the lifecycle of an aircraft, and only a limited amount of the overall energy consumption and emissions related to aviation. Recently, sustainability has also approached aspects related to production and manufacturing. Yet, most aspects related to end-of-life solutions, maintenance and (most of) operations and production of aircraft and airports have been neglected in the life cycle analysis.

Circular economy principles applied to aviation can enhance the already ongoing research activities and the industrial implementations of sustainable solutions in aviation, by expanding their current fields of application (from local to global) and by initiating new solutions aiming to achieve an even greater impact.

In a nutshell, Circular Aviation is expected to support the implementation of circular and sustainable practices throughout all aspects of aviation, beyond in-flight operations and impacting in particular the design and the manufacturing of air vehicles.

LEGACY: WHAT IS CIRCULAR ECONOMY?

Following the Paris Agreement on Climate in 2016, every industry worldwide, thus including the European aviation sector, has been challenged with limiting global warming reducing greenhouse gases (GHG) emissions. Even before the Paris Agreement, the European Commission set several environmental goals in its 2011 Transport White Paper[1] oriented to *"growing transport and supporting mobility while reaching the 60 % [GHG] emission reduction target"*, *"developing and deploying new and sustainable fuels and propulsion systems"* and increasing the use of *"low-carbon sustainable fuels in aviation to reach 40 % by 2050"*. Furthermore, FlightPath 2050[2] highlights how aviation shall actively engage in *"protecting the environment and the energy supply"*, providing "*sustainable [...] connectivity for passengers and freights"*, and "*protecting the environment and enabling the use of sustainable energy and alternative energy sources"*.

This commitment from European institutions and governments, together with a growing environmental awareness in the European society, stimulates and supports the flourishing of numerous initiatives towards industrial sustainable development. The most frequently quoted definition of sustainable development is taken from the so-called Brundtland Report[3] and it states that: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*

Circular economy (or circularity) is one approach to engage with sustainability. A circular economy is an alternative to a traditional linear economy (which can be summarized with "make, use, dispose") in which resources are kept in use for as long as possible, extracting the maximum value from them whilst in use, then recovering and regenerating resources from products at the end of each service life (Figure 1). Circular economy is "a new way to design, make, and use products within planetary boundaries. Shifting the system involves everyone and everything: businesses, governments, and individuals; our cities, our products, and our jobs"[4].

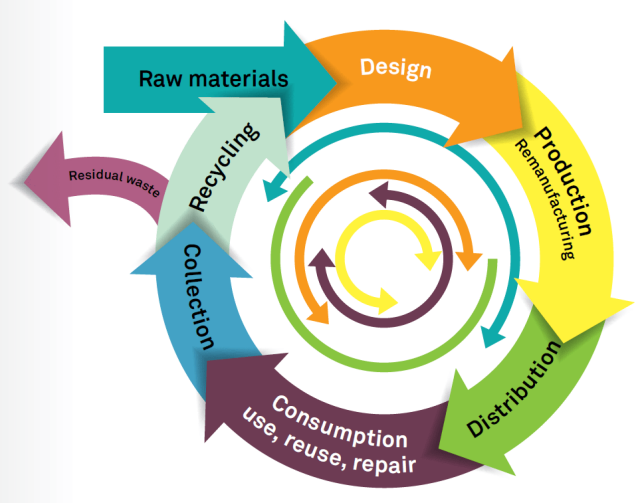

Figure 1 : Circular economy wheel

At European level the transition towards a circular economy model has been illustrated in the EU Circular Economy Action Plan[5]. In this plan, the principles of circular economy are promoted and their application encouraged throughout different industries, in a broad range of areas, from production, to waste management and development of regulations. Currently, in the aviation sector, sustainability and circularity initiatives focus

[1] Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system (COM(2011)144), European Commission, 2011.
[2] Flightpath 2050, Europe's Vision for Aviation, Report of the High Level Group on Aviation Research (EUR 098 EN), European Commission, 2011.
[3] Our common future, World Commission on Environment and Development, 1987.
[4] Definition by the Ellen MacArthur Foundation.
[5] Closing the loop - An EU action plan for the Circular Economy (COM(2015)614), European Commission, 2015.

on propulsion and waste management, in order to reduce the GHG emissions from aircraft operations and the amount of waste produced in airports and during flights. The EREA Future Sky Energy theme focuses on developing innovative solutions to reduce the GHG emissions related to propulsions, by exploring new aero-engines concepts, hybrid-electric solutions and the implementation of sustainable aviation fuels, such as hydrogen. In reality, emissions due to in-flight operations only cover part of the lifecycle of an aircraft, and only a limited amount of the overall energy consumption and GHG emissions related to aviation. In general about 45% of the global GHG emissions can be attributed to the production of materials and other products[6], and at least 30% of GHG emissions related to aviation are generated from sources unrelated to aircraft active operation, or propulsion[7]. Recently, sustainability and circularity aspects are slowly being introduced in production and manufacturing. Yet, the majority of activities related to aviation has been so far neglected in the life cycle analysis, leading to a partial, thus inefficient, implementation of sustainable and circular approaches. In order to achieve the target reduction in GHG emissions and other environmental goals, the overall aircraft life cycle, from cradle to cradle, needs to be reassessed and new industrial solutions developed and implemented.

The EREA Future Sky Circular Aviation Theme offers a thoroughly and complete view on the life cycle of aircraft, airports and, in general, aviation-related operations, broadening the number of aspects which shall benefit from circular solutions in order to transition to a sustainable aviation business.

CHALLENGES

Implementation of circular economy principles is progressing in a broad variety of sectors, from consumer product development, to fashion, to urban design. Most of the challenges faced in other sectors during this transition from linear economy to circular economy are similar to the challenges which the aviation industry needs to address in order to successfully implement its own circularity solutions. Those similarities shall favour and encourage inter-industry cooperation, in the true spirit of circular economy.

CIRCULARITY IN THE DESIGN AND DEVELOPMENT LIFE-CYCLE

Aviation is already successful in the implementation of some of the approaches which are now connected to circularity; aircraft are products designed to have a long service life (in the order of magnitude of several decades) and maintenance, repair and overhaul (MRO) is an area of significant expertise in aviation. Nonetheless, aircraft and airports are far from being fully circular products; a clear example is the limited focus on end-of-life aspects, such as recycle of material and reuse of components. Many circular and sustainable R&T activities are ongoing, for example in researching recycling of composite materials or in achieving zero waste production in airports. Such solutions are mainly local, not yet integrated in the global aviation environment, due to the low TRL of the current circular solutions and to their non-competitive costs compared to linear economy solutions. Also, these existing circular activities are limited in their impact as applied to products which had not been originally designed to be circular. The only effective way to incorporate circularity is to implement circular design principles when developing new products, at the conceptual design phase. It is important to remark that design frameworks and life-cycle analysis and assessment methods specific for circularity require further research, before being optimized for application to the aviation sector.

CIRCULARITY AND SOCIETAL CHANGE

With a rising in environmental awareness, more demand from the society and the passengers is to be expected for sustainable and circular services. Such shift of habits in the new generations has already been observed in other sectors; aviation should also actively implement and advertise the transition to Circular Aviation.

[6] Completing the picture: how the circular economy tackles climate change, Ellen MacArthur Foundation, 2019.

[7] Environmental assessment of passenger transportation should include infrastructure and supply chains, M.V. Chester and A. Horvath, Environ. Res. Lett. 2009.

Currently the general public perceives aviation as highly polluting, and the general press tends to present a limited and biased view of the aerospace sector. Several sustainable and circular initiatives are ongoing within the aviation sector, particularly in the field of more efficient aeronautical engines, electric flying, alternative fuels, lightweight design, optimized flight routes for minimal consumptions and MRO. Unfortunately, those activities are not always visible or understandable for the general public. Some sustainable initiatives in aviation have found large consensus, such as the widely advertised Etihad "Plastic-Free" long-haul flight on April 22nd 2019[8] or other local initiatives of airports and airlines to reduce plastic consumption and recycle waste. Therefore, implementing circularity in aviation sector requires efforts not only related to developing the technological solutions, but also towards engaging the public and emphasizing that circularity and sustainability are not in opposition to quality and safety.

CIRCULARITY AS NEW WAY OF MAKING BUSINESS

The aviation sector is already familiar with some of the business models typical of circular economy, such as aircraft lease, cabin refurbishment, and retrofit solutions. Still, most of the business aspects of the life cycle of aircraft and airports are not fitting the circularity principles. The lack of comprehensive circular business models is an obstacle for companies engaging in circularity to obtain loans or capitals for investment, but also, more simply, to perform within the current linear economy, making the new design solutions non-competitive. On the positive side, sustainable and circular solutions within aviation are being increasingly demanded from end users (airlines, passengers) and service providers (airports). Such demand can provide the business case to support the development of circular business models, reinforcing the transition to Circular Aviation. Local, national and European governments should support aviation businesses not only to develop new solutions fitting a circular economy, but also to manage the transition that the businesses themselves, and their workforce, shall undergo.

CIRCULARITY AS AN OPPORTUNITY FOR THE TECHNOLOGICAL COMPETITIVENESS

The EU repeatedly insists on the very strategic nature of the aircraft industry to uphold its global leadership in aviation, while raising its ambition of defending the highest living condition for its citizens. In the EU Circular Economy Action Plan, circularity has been identified as a way to *"boost the EU's competitiveness by protecting businesses against scarcity of resources and volatile prices, helping to create new business opportunities and innovative, more efficient ways of producing and consuming"*. When the objectives of EU Circular Economy Action Plan are combined with those of the EU Transport White Paper, there is no doubt that circular economy shall favour a variety of business opportunities connected to aeronautical technologies. Implementing circular solutions and products is now limited mainly by the lack of technological solutions. To support circularity, two different groups of solutions need to be developed: one group of solutions concerns how to transition existing aircraft and airports from the linear economy model, into which they had been designed and developed, to a circular economy model, while the other group of solutions concerns how to initialize new aircraft and airports with a circular approach.

CIRCULAR AVIATION – ACTION LINES

To address the challenges inherent to the implementation of circularity in aviation, several priorities have been identified. Within those thematic priorities, several topics for research and development projects can be foreseen; the list of topics mentioned in this white paper is far from being exhaustive. The solutions developed in such projects, once successfully implemented within the aviation business, will contribute significantly to making aviation circular.

[8] https://www.etihad.com/en-us/about-us/etihad-news/archive/2019/etihad-airways-to-operate-single-use-plastic-free-flight-on-earth-day-as-part-of-its-commitment-to-sustainability/

DESIGNING AND PRODUCING THE CIRCULAR AIRCRAFT

The most effective way to incorporate circularity is to implement circular principles at the conceptual design phase of an aircraft. This is because both design and manufacturing aspects need to incorporate circular economy principles in order to transition to a circular design and manufacturing. The following topics have been identified as priorities regarding the design and the manufacturing activities:

- Circular design solutions
  As design solutions with focus on extending durability (for example via modularity solutions), ease to repair approaches, disassemble, reuse of components, eco-design and recycle shall be encouraged and prioritized, design practices, related tools, and frameworks need to be developed and/or adapted for applications in the aviation industry.
- Choice of materials
  Resourcing and environmental considerations need to be included in the existing methodologies used for the material selection at design stage, and models to assess the environmental impact of engineering materials need to be developed. The use of recycled and bio-based materials shall be favoured, while the harvesting of new resources, especially critical materials, shall be minimized. Research towards the identification or the development of alternative materials shall be fostered. Material properties and models for recycled and bio- materials shall be investigated, to support the necessary qualification and standardization activities.
- Resourcing of (recycled) materials
  Materials for circular aeronautical applications shall be resourced from the materials already extracted and present in already disposed products. The limited use of recycled materials is linked to the lack of feasible recycling methods and uncertainties about the qualification and safety of such materials, as regulations on the topic are still being developed. To tackle those issues, urban mining activities, already introduced in cities and communities, can be phased in airports and aircraft boneyards. Next to availability of recycled materials, qualification activities need to be initiated and supported by standardization committees and governments.
- Circular Manufacturing
  In order to limit or altogether avoid scrap parts, manufacturing waste and excessive material and part testing, optimization of manufacturing processes and of the use of materials shall be investigated by developing, validating and fully integrating first-time-right solutions, such as virtual manufacturing, virtual testing and digital twin frameworks. In addition to this, implementing circular design considerations can be foreseen to have a significant impact on the manufacturing equipment, facilities and related logistics. Solutions towards envisioning manufacturing facilities as close systems shall be assessed and implemented, with local facilities for production of energy and for treatment of waste, targeted at zero waste, zero GHG emission and minimum energy consumption. Local manufacturing solutions shall also be investigated (for example 3D printing technologies).

FLYING CIRCULAR

The flight experience and the connected operations are the most visible aspects of aviation to society, and, consequently feed the societal perception that the majority of the GHG and of other pollutants emissions related to aviation are connected to its operations. As a consequence of this, the first steps of the aviation industry into sustainability had been linked to propulsion and reduction of fuel consumption. More aspects of aircraft operations have been identified which shall benefit from the application of circularity principles and solutions:

- Recycling activities
  Airlines are already actively implementing solutions to provide a sustainable on-board experience (as discussed later in this White Paper) by implementing no plastics and no waste solutions and by recycling the textile materials used for interiors; more solutions related to a circular on-board

experience shall be investigated, focusing on integrating safety regulations and lightweight requirements with sustainable practices (for example, fire-retardant compounds used for interiors prevent recycling of fabrics and plastics).

- Ground operations
  Implementation of digital records to manage and record ground operations shall be favoured, having the advantages of a reduced footprint and improved traceability and security of data. Other ground operations which need to be targeted for innovative solutions are related to taxiing; electric taxiing solutions shall be investigated which can reduce also noise pollution, as shall innovative concepts for runways (for example, energy harvesting or self-healing asphalt).
- Maintenance, repair and overhaul (MRO)
  Current aviation practices connected to MRO fit perfectly with circularity principles. Aircraft structures are designed to last longer than most commercial products on the market; in order to achieve such long product life, MRO solutions are of paramount importance. In addition to build on the already significant experience in the field of MRO to support life extension programs, further research for integrated MRO solutions and predictive and prescriptive maintenance concepts, to optimize usage of aircraft and fleet shall be supported, in particular towards broadly implementing structural health monitoring systems and developing advanced non-destructive inspection and repair methods compliant with circularity principles.
- (Hybrid-) electric aircraft and alternative fuels (covered in the Future Sky Energy theme)
  As the use of alternative of fuels has an impact on the performance of aeronautical engines, the development of innovative engines and systems architectures, fully compatible with alternative and sustainable fuels, shall be studied. Modification in the architecture of aeronautical engines shall foster research in innovative aircraft configurations. Further research towards a higher circularity level in the design, manufacturing, production and life-cycle management of high performance batteries (and other electrical power supplies) and bio-fuels shall be fostered.

THE CIRCULAR LIFE CYCLE OF AVIATION

In order to evaluate the real impact of aviation on the environment, appropriate life cycle analysis methods and indicators need to be identified and implemented. Already during the design phase, the complete cost of the entire life cycle, from cradle to cradle, shall be evaluated and design decisions based on this. In the current life cycle assessments, many factors are neglected, partly due to the difficulty in acquiring relevant information, but also because some aspects are considered to fall beyond the business case of the manufacturer. Of particular relevance are the considerations about the end-of-life, from how to reuse or recycle components and systems, all the way down to how to recover and recycle the individual materials used; all those aspects need to become an integrated part accounted for in the developed Circular Aviation life cycle analysis tools and business models.

In addition to incorporating circularity and cradle-to-cradle life cycle assessment during the development of new aircraft, research activities need to be established focusing on end of life aspects related to the current fleet: recycle, reuse, resell, and recover practices are being developed in other sectors. Applicability of those practices to aviation shall be investigated. Challenging end of life objectives, for example reuse and recycle up to 99% of aircraft parts, shall encourage research and investments.

AIRPORTS AND AIRLINES AS CIRCULARITY AMBASSADORS

Even before boarding the “circular aircraft”, passengers and society experience aviation in airlines and airports. Therefore, implementing circular and sustainable solutions in the daily operations of airlines and airports can have a massive societal impact, well beyond aviation. Several airlines have already initiatives in place, in form

of CO_2 compensation, reduction of waste, ban of single-use plastic items[9], and investments in electric flying solutions[10]. Airports are also aiming at achieving objectives such zero waste or being run on solar or wind energy only[11]. As for many other examples of sustainable initiatives, currently the examples mentioned are of local nature and limited impact. The following actions have been identified to support airlines and airports in their sustainable development:

- Circular architecture of airport infrastructures
  Airports should not only operate in a sustainable and circular way, but they should also be designed and built in a circular way. Examples of circular architectures are becoming common within various "Circular Cities" initiatives[12]. Solutions to incorporate circular architecture within the specificities of airports shall be investigated and implemented.
- Synergistically engaging airlines, airports and local communities
  As circularity advocates the interaction among different industries and sectors to reach its full impact, a fundamental step is to integrate the airlines' solutions with the airports' solutions and infrastructures, and then favour the integration of the airports' infrastructures with the local community infrastructures, in order to ensure that local communities shall benefit from the developed circular solutions. Last, but not least, the transition of airlines and airports to Circular Aviation shall translate in new job and business opportunities, from which local communities shall have a direct, long term benefit, without impact on the community's quality of life.
- Integrated zero-emissions transportation networks for passengers and freight
  The continuous growth of the aviation industry is impacting the transportation networks around the airports, creating traffic in the local communities and delaying passengers and freight, and therefore affecting the air traffic schedule. Solutions for guaranteeing accessibility to the airport in synchrony with the flight schedule shall be implemented, by investing in zero-emission, autonomous and on-demand transportation.
- Circular business models for aviation industry
  Developing a successful circular business faces the obstacle that current business models are based on linear economy principles. Ad hoc business models for circular economy are being developed, and evaluation of applying circular models to aviation shall be researched. Airlines are already familiar with alternative models to full ownership of aircraft, such as leasing or taxi services. The applicability of such models shall be evaluated for other aspects of the aviation industry, from airports to cabin interiors.

CIRCULAR POLICIES AND REGULATIONS

In order to support and implement the transition towards a Circular Aviation, policies and regulations, oriented to promote, apply and industrialize the circular solutions developed as part of the previously described thematic priorities, must be established. The aim of such policies and regulations shall not be limited to guiding the aviation business towards more sustainable practices, but also shall provide the regulatory framework which guarantees that the current safety standards of the aviation industry are not impacted by the transition from linear economy to circular economy.
Within this theme, the following topics have been identified as priorities in order to support the technological research topics indicated in the Circular Aviation theme:

- Regulations about material characterization (for example, in case of recycled materials);
- Regulations about technical requirements for the reuse of parts and components;
- Regulations aiming at guaranteeing security and safety aspects of reused components;

[9] https://klmtakescare.com/en/
[10] https://www.flightglobal.com/news/articles/easyjet-outlines-progress-on-electric-jet-453088/
[11] https://www.airport-technology.com/features/worlds-environmentally-friendly-airports/
[12] https://www.thegreenhouserestaurant.nl/over-ons/

- Establishing procurement practices based on circularity and sustainability criteria.

ORGANISATIONAL REMARKS

Achieving the transition to Circular Aviation and addressing the thematic priorities highlighted in this document can only be successful by establishing close relationships among the organizations members of EREA and external partners and by engaging experts in circular economy in other sectors than aviation.

Thanks to its strategic position between educational institutions and industrial partners, EREA can help keeping the Circular Economy framework visible for the various stakeholders involved in developing individual solutions.

TOWARDS AN ENLARGED AUDIENCE

With regard to challenges embedded in Circular Aviation and considering the complex landscape from which they stem, the range of partners to be involved by EREA in Circular Aviation activities is to be extended to the following ones:

- The aviation industry,
- The European network Small and Medium Enterprises,
- The airline and airport network (ACI Europe),
- European organisations (EASA, JRC…),
- EU policy-makers,
- The academic and university research centres,
- Joint Undertakings or Joint Research Initiatives,
- Similar eligible entities from non-EU countries.

Through Circular Aviation, the EREA intends to articulate with relevant partners shared views endeavouring to pave the way for common projects. Further to the challenges introduced above, these projects may target other, still unforeseen, priorities.

TRAINING AND EDUCATIONAL ACTIONS

The European Aviation Science Network (EASN) is an official partner of the EREA, specialized in educational purpose. Considering the long term and societal impact of the priorities connected with Circular Aviation, engaging future generations is of paramount importance. It is therefore suggested to develop a common approach on this topic in the prospect of raising awareness of teachers and lecturers from Universities and Engineering schools and to be more attractive for young professionals. It is noteworthy that this kind of educational actions, once well-defined and duly introduced, may also be supported by the European Commission.