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AIRCRAFT RECYCLING SYSTEM OPTIMALIZATION AND AIRCRAFT SECTIONS RE-USE POSSIBILITIES AFTER THE END OF THEIR ECONOMIC LIFE

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Abstract

Purpose of this article is to evaluate re-use of sections from retired aicraft for further usage and additional optimalization of recycling and re-use of materials used in aircraft construction. With hundreds of commercial airplanes retired every year, the need for innovative approaches in recycling process rises. The concept of re-using parts from retired aircraft is not new. Before scrapping, valuable parts are of course stripped of the airplane. The article assesses if there is possibility to re-use parts and sections that usually end up scrapped in aviation and under which circumstances. Its first part is focused on analysis of procedures currently utilized during aircraft recycling, including brief description of decomissioning process, current state aircraft recycling in general, processes of disassembly and dismantle, existing facilities, description of recycling of alloys and composite materials. Second part deals with legislative, technical and environmental options of aircraft recycling and re-using aircraft sections. Third part focuses describes current parts market, together with proposal how to make it more efficient, current and possible future trends concerning aircraft recycling and re-use of materials and comparison of recycling between USA and Europe

Keywords

Aircraft recycling, Parts reclamation, Aerospace industry, Composites, Optimalization of recycling

1. INTRODUCTION

Airplanes are rightfully considered one of the most technologically impressive inventions designed by man. In over a century of existence, they have gone through many evolutionary stages. Far less emphasis has been placed on issues relating to the handling of end of life aircraft. These often ended up abandoned at remote airfields. It was not until the advent of the new millennium, when it became apparent that alternative uses would be found for the materials used in their construction and the recycling of aircraft on an industrial scale began to be discussed. This article will describe the current recycling issues, its advantages and obstacles. In addition, it will also deal with the situation in the used parts market, but also with the issue of recycling composite structures, which are increasingly serving as a substitute for aluminium alloys and presenting new challenges in the sector. It will also outline possible alternatives for the reuse of units that have not yet reached the end of their technical life and ideas for streamlining some of the processes on the market. It is divided into three chapters. The first is an introduction to the subject, containing factors leading to scrapping, a description of dismantling and disassembly, the situation with parts, equipment and an approach to recycling the most commonly used materials. The second chapter deals with legislation and recommendations related to the processes, addresses the environmental impact of aircraft recycling and presents solution of the use of decommissioned machines in the armed forces as a possible model for civil aviation. The third describes the sale of used parts with ideas for further improvement, future trends in the use of recycled materials, and comparisons aircraft recycling between the US and Europe.

2. ANALYSIS OF PROCESSES THAT ARE CURRENTLY USED IN AIRCRAFT RECYCLATION

This chapter describes the methods currently used to recycle aircraft parts and assemblies. Every year, hundreds of transport aircraft are retired by operators around the world as they reach the end of their technical service life or it is no longer economically viable to operate them. According to the International Air Transport Association (IATA), the average age of transport aircraft at the time of retirement is 27 years. Given the constant growth in air traffic in the years prior to the outbreak of the COVID-19 pandemic, it is estimated that the number of retired aircraft will increase in the coming years. A small proportion are being converted to carry cargo after retirement by passenger carriers, with subsequent operation by freight carriers. Most of them, however, are decommissioned and gradually dismantled by specialized firms. In today's world, the emphasis on recycling is considerable in all sectors and will grow in the future. The concept of recycling in the aerospace industry is a relatively new, it began to emerge in a larger degree at the turn of the millennium, in connection with the activity of the world's largest commercial transport aircraft manufacturers at the time, Airbus and Boeing. The aim was to prevent the trend of aircraft languishing at various airports after being retired and stripped of usable parts. The European company Airbus founded the Process for Advanced Management of End of Life Aircraft (PAMELA) project, while the American Boeing came up with AFRA - Aircraft Fleet Recycling Association - in 2005. AFRA, which includes aircraft manufacturers such as Boeing and Embraer, engine manufacturers such as Rolls-Royce, as well as companies specialising in aircraft disassembly and parts distribution, recycling companies, leasing companies and research and development centres, has published a series of guidelines known as BMPs, which have become the industry standard in the United States and Europe. Companies specializing in dismantling and recycling that are certified according to them are considered a reliable source of quality parts. The Association provides the procedures and tools necessary to increase the economic return on scrapped aircraft and contributes to the further expansion of recycling by making it an attractive option for a greater number of operators who, until recently, have preferred to simply park scrapped aircraft in desert areas. Its European equivalent, the PAMELA is supported by the European Commission. The aim at its inception in 2005 was to demonstrate that a greater proportion of scrapped aircraft are recyclable than the previously stated 50%. As part of the experiment, Airbus carried out a complete disassembly and recycling of an Airbus A300 transport aircraft, proving that up to 85% of the total weight of the machine could be reused or recycled. Less emphasis was placed on the quality and purity of the material recovered, but according to Airbus, most of the recovered material and parts could be reused in the aerospace sector.

2.1. Decomissioning, Disassembly, Dismantling

Operators usually take the decision to retire an aircraft when the machine is approaching the end of its service life. For commercial carriers, this is usually divided into technical and economic. Technical service life is determined by the manufacturer on the basis of fatigue tests that are part of the type certification of a given type when it enters service. The economic lifetime is not defined. If the operator considers that it is more economically viable to acquire a new aircraft due to rising operating costs, and there is no interest in the market for a given aircraft, it will be retired. If the owner decides to sell it to an aircraft dismantling company, several options are possible, such as selling the entire aircraft in the condition it is in, at the location where it is located, which imposes minimal time and logistical requirements on the owner, with the dismantled parts already being the property of the new owner. A more time-consuming method is to disassemble higher value parts such as engines, auxiliary power units or landing gear, in-house with subsequent sale. If it has sufficient space, the company can decommission the aircraft and gradually dismantle the parts it installs in the remaining aircraft in its own fleet or for resale

Disassembly means the removal of components and parts that will subsequently be reused as spare parts on the aircraft. After removing the usable parts, the rest of the machine is dismantled. The main objective is to recover part of the money spent together with a positive environmental impact of the recycling process. This process must be carried out by an approved maintenance organisation. Parts dismantled by an organisation without the necessary approval cannot be used as spare parts. Airlines having their own MRO organisation, can handle the process independently. As mentioned above, parts must have records of their history, called logbooks, must be removed and subsequently stored in accordance with the regulations. Typically, the process involves the removal of engines, auxiliary power unit (APU), ram air turbine (RAT), avionics, flight control systems and engines, hydraulic systems, landing gear including wheels and brakes, pumps and electric motors.

At the start of dismantling, there are no parts in the machine that could be installed on another airworthy aircraft. The reuse of any parts is strictly prohibited. The process is not required to be carried out by an approved maintenance organisation. It will normally start after the aircraft has been removed from the aircraft register. Prepare Your Paper Before Styling

2.2. Current state of aircraft recycling

Recycling can be defined as the process of collecting, sorting and reprocessing used materials for further use. It therefore reduces the demand for extraction of natural resources, the energy consumed for it and prevents waste of resources. Its main objective in the manufacturing industry, which includes aerospace, is to save the environment by reducing greenhouse gas emissions, preventing water and soil pollution and, last but not least, contributing to the creation of employment opportunities. There is currently no legislation on procedures for dealing with end-of-life aircraft. Recycling is therefore voluntary. This probably has something to do with the relatively small number of aircraft involved until recently. The vast majority of recyclable components from aircraft are composed of valuable metals and alloys which, once recycled, become materials that can be reused. Nowadays, it is mainly metals that are recycled from aircraft, which are available in large quantities, while the less abundant ones end up as waste. The quality of recovered materials also varies, as the emphasis is on quick and inexpensive dismantling of the aircraft rather than on the separation of the individual materials. The alloys that are used in aircraft construction are aluminium, magnesium, nickel, cobalt, steel and titanium. Nickel and titanium alloys are mainly used in engine parts. Aluminium alloys clearly have the largest share.

2.2.1. Recycling of aluminium alloys

For decades, aluminium alloys have been used as the primary structural element of major aircraft parts, both military and civilian. Advantages include relatively light weight, combined with sufficient temperature resistance. Their manufacture is mastered, established and relatively inexpensive. Due to the not entirely advantageous properties of pure aluminium alloys, other elements such as copper, zinc, manganese, silicon and magnesium are commonly added. Of all the aluminium alloys, those used in aerospace have the highest volume of alloying and are the most expensive. Alloy grades 7000, 6000, 2000 and 5000 are used in aircraft, most commonly with the specific designations EN 7075, EN 6061, EN 6063, EN 2024 and EN 5052. It has been reported that, compared to the processing of raw material, the use of recycled aluminium alloys saves up to 90% of the energy otherwise spent on the electrolysis of liquid aluminium. The recycling of aluminium alloys begins with sorting based on piece size and grade composition. Pieces with a matching grade guarantee high purity of the resulting material, free of contaminants. These are crushed, melted and then formed into cast parts during refining. They are easier to mix during repeated melting. Laser spectrometry labeled LIBS is widely used in the recycling of large aircraft assemblies and components. It allows the elemental content of an alloy to be accurately classified and thus the specific designation of that alloy to be determined. It is not only used for aluminium alloys, it can reliably determine any type of alloy.

2.2.2. Recycling of titanium alloys

Titanium alloys are widely used in aerospace due to their high strength, good corrosion resistance and high heat resistance. Unlike other commonly used structural materials, the manufacturing process is complicated and lengthy, which also results in its higher cost. The titanium extraction process begins with its identification, classification, surface cleaning and separation from the residue. Depending on the composition of the individual alloys in relation to the elements added, these are then remelted and recycled. The most widely used titanium alloy in aerospace applications is Ti-6Al-4V, which has a high proportion of aluminium.

2.3. Issues with composite materials recycling

In recent years, there has been a significant increase in the use of composites in the construction of both civil and military aircraft. Their main advantage is weight reduction. Boeing has saved up to 20% percent of the weight of its 787 Dreamliner by replacing aluminium alloys with composites. Other advantages include their flexibility, reduced maintenance requirements, reduced number of parts, and they are not subject to corrosion and expansion at high temperatures. While the advantages of their use are obvious, the subject of their disposal or recycling presents new challenges for the industry. Of course, composites were also used in older aircraft, but with their proportion of the structure being around 10 to 15%, the issue of recycling was not as important. This will, of course, change in the future. Compared to previous materials, composite waste is already generated in the manufacturing process. Glass and carbon fibre are most commonly used in aircraft construction. Carbon/glass fibres and epoxy resins are the two main components of composites, which are present in the form of a pre-impregnated roll of material prior to the manufacturing process. In the past, this roll was cut by hand, resulting in a very low material recovery rate of only around 40%. With the use of automation, it has been possible to increase the accuracy considerably, as well as to reduce the time required for production. At the same time, today's automated trimming machines are able to mark the piece to facilitate identification at later stages of the process. These rolls have a specified lifetime in their raw state, beyond which they cannot be used again without a recertification process, which, however, further increases the cost of production. Despite advances in manufacturing, the proportion of used material relative to waste is still relatively high. As the use of composites grows, so will composite waste. As already indicated, recyclers face a major challenge in terms of cost and time efficient recycling of composites. There are currently a number of approaches to recycling composites.

2.3.1. Mechanical recycling

The simplest method is mechanical recycling. It can be used for almost all composite materials, but it is mainly used for glass fibres, its technology is well mastered and it is available at a relatively low initial cost. Pieces of materials are first cut or crushed to reduce them to a size of about 50-100 mm. These are then further reduced to dimensions on the order of tens of µm by high-speed shredders. After shrinking, they are separated by sieves into parts with a higher fibre content and parts with a higher resin content. In the case of glass fibre reinforced polymers, these fibres are crushed once more after sorting. These are already considered as raw materials which can be further used. No chemicals or high temperatures are required for mechanical recycling. Compared to newly produced fibres, recycled fibres have lower strength as well as weaker molecular bonds as a result of the fact that the fibres are broken. The reduction in mechanical properties, which can be in the range of 18-30 %, is a major obstacle to the use of recycled fibres. Recycled fibres are therefore only subsequently used in lower grades of composites.

2.3.2. Thermal recycling

Two thermal methods are used for material extraction. The first is the fluidized bed method. It also involves combustion, but allows the material to be extracted in the form of fibres, while the burning of the resin matrix produces energy from which heat or electricity can then be generated. It can be used with both glass and carbon fibres. Initially, the composite material is mechanically cut into smaller pieces, which are then used to fill the fluid bed reactor. The device heats up fresh air that needs to be brought in. Epoxy resins require 550 °C, while polyester resins require 450 °C. When heated to 450°C, glass fibres lose up to 50 % of their tensile strength, while carbon fibres resist even higher temperatures better. The hot air stream breaks down the matrix and separates the fibres, which are then separated from the matrix by a swirling motion. Heavier materials such as metal pieces cannot be separated by the hot air. The resin from the matrix completely oxidizes (burns), generating energy. The surface properties of recycled fibres can be similar to newly produced fibres, but their overall characteristics can lead to limitations in further use.

The second thermal method is pyrolysis, which takes place at temperatures between 350 and 800 °C, without the presence of oxygen, when the organic part of the composite material is broken down into smaller molecules by the supply of hot air. These are converted into a gaseous or liquid state. Inorganic parts such as fibres, fillers or possibly small carbon particles remain in the solid state. By oxidation of the incoming air, these particles are burned off, resulting in clean fibres and fillings. It can also be combined with incineration to remove residual materials.

2.3.3. Chemical recycling

In chemical recycling of composites, the matrix degradation is carried out using chemicals and solvents such as methanol, propanol, but also water and others. Fibres extracted by chemical recycling should retain most of their original mechanical properties. On the other hand, being quite energy intensive, any research in this area is likely to focus on this area, in order to increase the economic attractiveness of solvolysis, which is already a newer and thus not fully explored/adopted approach in the field of composites recycling. Current developments are focused on experiments with different substances used both as solutions and as catalysts.

3. LEGISLATIVE, TECHNICAL AND ENVIRONMENTAL OPTIONS OF AIRCRAFT RECYCLING AND RE-USING AIRCRAFT SECTIONS

The second chapter of the article deals with the possibilities of reuse of aircraft units. As mentioned in the previous chapter, a large number of parts and components can be used from a scrapped aircraft. However, after their disassembly, a large part of the aircraft remains in one piece. This is made up of recyclable material and waste. After dismantling, some of the planes are parked and languishes somewhere on the periphery of airports, some are dismantled in order to recover the materials used in the construction. The challenges already described in the recycling process prevent the possibility of these materials being reused in the construction of newly manufactured aircraft. A small part may be converted to other uses such as various attractions, museum exhibits, restaurants and so on. The re-use of aircraft assemblies from retired planes is virtually non-existent in commercial aviation.

3.1. Examples of aircraft sections re-use from military aviation

However, if the issue of reuse of units is examined not only from the perspective of commercial/civil aviation, but also from the military perspective, it becomes clear that practical cases already exist around the world. The military aviation sphere is not only not subject to civil aviation regulations, but may have its own specificities in each country. With the end of the Cold War, defence budgets declined significantly, which in the vast majority of countries at the time affected both the numbers of aircraft in service and the numbers of new ones being purchased. This situation essentially persisted until the annexation of the Ukrainian peninsula of Crimea by the Russian Federation in 2014. When the United States armed forces are taken into account, a large number of aircraft that had not yet reached the end of their service life were decommissioned and stored in this context, victims of budget cuts due to their advanced age or the fact that they represented older modifications. The US armed forces have a very efficient system for dealing with unused aircraft. Most are flown or ground-transported to Davis-Monthan Air Force Base, Arizona, home of the 309th Aircraft Maintenance and Regeneration Group. Upon arrival here, the aircraft are preserved and stored so that they can be returned to service if required, with approximately 25 % of the machines actually returning to service. About 300 aircraft are disposed of each year. Compared to civilian aircraft after the disassembly, a considerably higher degree of disassembly is visible here. In addition to the normally disassemblied engines, landing gear, instrumentation, control systems, etc., there are missing forward fuselage sections, cabin overlays, wings or tail control surfaces. This may be due in part to the need to remove sensitive military systems before scrapping and recycling, which is provided by contracted civilian firms. The main reason lies in the aforementioned reduction in defence budgets. In the new millennium, it was to replace the current generation of US aircraft such as the General Dynamics (now Lockheed Martin) F-16 Fighting Falcon, the McDonell Douglas (Boeing) F/A-18A/B/C/D Hornet, the Fairchild Republic A-10 Thunderbolt II and, in part, the McDonell Douglas (Boeing) F-15C/D Eagle, the Lockheed Martin F-35 Lighting II family of aircraft. For a number of reasons, this program has suffered from significant increases in development costs and unit price as well as significant delays. As a result, the decision was made to extend the service life of the in-service equipment. Given the interim nature of this solution, the logical requirement was to keep the cost as low as possible. This was to be achieved by utilising units from stored aircraft that had lower sorties and were stored and maintained in ideal desert conditions. It is usually conducted as part of scheduled maintenance and is carried out by the component's own maintenance units, with the removal of parts from parked aircraft being carried out by members of 309th Group. The project is considered a success, the savings in time and money when compared to newly manufactured parts are not insignificant.

From a technical perspective, a similar approach could be applied to the repair of damaged civil aircraft, for example. Of course, this would require considerable financial and labour effort, multiplied by the fact that commercial aircraft significantly outnumber the above-mentioned examples of military machines in terms of size, and thus the actual execution could be even more technically challenging, depending on the damage and the extent of repair required. In such a case, it would be up to the operator to assess whether it is more economically viable to scrap the machine or to attempt to repair it.

3.2. Legislative aspects of recycling and used parts

There is currently no binding, internationally recognised legislation that mandates aircraft to be dismantled and recycled after scrapping. It is logical to assume that any future regulations should be under the umbrella of ICAO, which is currently responsible for international coordination in the field of civil aviation. Although ICAO has recently put the aircraft retirement process and its challenges on its agenda, it also believes that the established so-called Industry Best Practices represent a better alternatives to regulations, either governmental or through ICAO. Nevertheless, it participates in the aircraft retirement process through the Standard and Recommended Practices (SARPs) contained in the Annexes. For example, the procedures contained in Annex 6 (aircraft operations), Annex 8 (aircraft airworthiness) or ICAO document 9760 (airworthiness manual) are important in terms of handling parts that will be reused. Other regulatory authorities involved in the retirement and dismantling of aircraft are national or regional environmental authorities and national/regional aviation authorities, represented by EASA in Europe and FAA in the United States. Their competence in the scrapping process mainly extends to the reuse of disassemblied parts. From a European Union perspective, it is important that the disassembly of the aircraft and the maintenance of the parts is carried out by a company certified by EASA as an approved maintenance organisation. The Agency has issued 5 regulations concerning maintenance organisations. All salvaged parts are subject to a regulation known as EASA Part M- Continuing airworthiness requirements, which is basically the requirements for maintaining the airworthiness of an aircraft, including all its parts and airframe assemblies. The next regulation is known as EASA Part 145 and relates directly to the performance of maintenance. It is the European standard for the certification of organisations providing design, manufacture, operation and maintenance of aircraft and their components. Although it falls under EASA, Part 145 is also aligned with FAA standards, so a company that is based in both the United States and Canada and is certified by the FAA as a maintenance center can also obtain Part 145 and improve its market position. In addition to the participation of the regulatory authorities, whose powers are mainly concentrated on the dismantling process, associations formed by companies in the industry, such as AFRA or IATA, are also involved in the retirement of aircraft. They are also involved in the dismantling process and the procedures set out by them are also recommended by regulatory bodies such as ICAO. IATA has developed guidance that guarantees operators and owners an economical, environmentally friendly scrapping of the aircraft that meets all legislative requirements. The document is entitled Best Practices for Aircraft Abandonment (BIPAD) It does not represent binding regulations. It is aimed at aircraft operators to give them a coherent picture and to motivate them to scrap the aircraft according to IATA procedures. Given that business and operating conditions differ from company to company and that the relevant laws also differ from country/region to country, it is not possible to create standard procedures that are applicable in every situation. The document is therefore mostly focused on general procedures, description of processes and information on applicable legislation. Another association is AFRA, which was created as an initiative of Boeing. Although it currently has dozens of members, there are no air carriers or regulators among them. It provides certification/accreditation to companies in the industry on a voluntary basis, which makes either mined parts or materials better priced. It is the leading international association in the recycling industry and the author of a document known as Best Management Practices, which is mainly aimed at companies specialising in aircraft dismantling, disassembly and recycling. It is appropriately complementing IATA's BIPAD, together they form an environmentally acceptable solution to aircraft scrapping.

4. DESIGN OF APPLICABLE SOLUTION FOR RECYCLED MATERIALS

4.1. Re-certified parts market

The current situation in the commercial aviation sector is marked by the ongoing COVID-19 pandemic and, more recently, the aggression of the Russian Federation against Ukraine, which has led to the announcement of trade sanctions by the European Union, the United States of America, Canada, Australia, New Zealand and Japan, with the civil aviation sector being one of the affected areas. Airbus and Boeing have already announced that they are suspending support for their products, including the supply of spare parts in the Russian Federation. Given the fact that these make up a large proportion of the country's civil transport aircraft, the decision will have consequences. Paradoxically, this may contribute to the growth of the used parts market, which Russian operators may seek to purchase through various intermediaries in the future. Any reciprocal action from the Russian side will have a limited effect, due to the fact that the Russian share of the global market is minimal, even negligible in the countries mentioned. However, at the time of writing, active fighting is still ongoing and negotiations between the involved parties are not yielding any practical results, so it is too early to draw any conclusions. In contrast, the impact of the COVID-19 pandemic on the sector is clear. Compared to its early days, it is easier to predict developments and operators can plan more effectively on this basis. Significant numbers of aircraft stored and subsequently dismantled have resulted in the market being flooded with large numbers of used parts. This, together with the low demand caused by the fact that the remaining aircraft were operated at a significantly lower level of activity, resulted in a significant drop in the value of the parts. The existence of the Internet has greatly simplified, accelerated, and globalized the parts sales process, while significantly reducing the possibility of an aircraft remaining grounded due to an unavailable parts. However, it is not possible to completely prevent the latter situation. New innovations in the way spare parts are procured could further reduce the likelihood of this phenomenon, which usually results in flight delays, cancellations or the need to lease a replacement aircraft. A potential solution could be to access the maintenance of selected used parts on the basis of a service contract with the parts owner. Similar contracts exist with parts manufacturers. In principle, this would work by the aircraft operator paying a monthly lump sum to the parts owner. In addition to the value of the part itself, this could also be based on the number of aircraft of a given model in the operator's fleet. In this case, the owner would have the parts ready in stock and they would be dispatched to the operator as soon as possible if needed. Such an approach is of course particularly suitable for airlines serving shorter routes or a defined region where the part can be delivered cheaply and quickly. Otherwise, the parts owner would probably have to operate a network of warehouses, but such a solution means high costs associated with transport, area and staff. A more cost-effective alternative would be a pool approach. This would consist of the owner providing the aircraft operator with a pool of spare parts that are immediately available. However, the monthly fees for this option will understandably be higher. The other option is an exchange in the sense that the spare parts supplier sends the operator a new or repaired part, the operator sends the non-functioning part to be repaired at the operator's expense in a shop. If the part is irreparably damaged or has reached the end of its manufacturer's service life, it must be destroyed in accordance with the regulations. Some parts may continue to be used for non-flight activities, e.g. as teaching aids in the training process of personnel, whether flight or ground. In this case, the part must be visibly damaged e.g. notched, marked 'non-serviceable' and/or distinctively colour coded to prevent its intentional or unintentional reuse on an active aircraft, as this constitutes a major flight safety violation.

4.2. Trends in aircraft recycling and future development

Currently, the concept of the so-called circular economy, an alternative to the traditional economy, is gaining prominence in various industries. It places great emphasis on minimising waste and preserving the long-term value of materials. This approach is driven by resource constraints, pollution, production limits, etc., which have made the original 'take, make, dispose' approach unsustainable. Used products quickly lose most of their value and end up as waste in landfills or simply abandoned in various places. Given that aircraft are built from expensive and high quality materials, they should be at the forefront of interest. While aircraft recycling is still a relatively new process, building parts and components for the aerospace industry from recycled materials is currently virtually non-existent. The challenges of the recycling process that cause this have already been described and are mainly related to the quality of the recovered materials. However, these materials can be used in other areas and sectors. In the future, it is expected that there will be a cost-effective separation of individual alloy layers and materials during recycling, which could allow aluminium alloys to be reused in the aircraft structure for less critical parts with lower or medium loads, such as flaps. Recycled plastics have degraded properties compared to newly produced ones, which limits their further use and understandably prevents reuse in the aerospace sector. At the same time, it should be added that the plastic components used on aircraft, especially in the interior, are not very critical from the point of view of flight safety, and therefore recycled materials may be used in the future. The reuse of composite materials faces similar challenges as plastics. For both, waste is already generated during the production process. Carbon fibre is increasing in aircraft construction at the expense of aluminium alloys, where both the manufacturing process (no waste) and the recycling issue are better managed. Uses are mainly sought for carbon/glass fibres as the resin is removed in the recycling process. There is currently little interest in recycled glass fibres and their price is low, so it is not economically viable to recycle them. With carbon fibres the situation is different. Because they are cut into smaller pieces when recycled, they cannot be reused to produce products of comparable quality to those made from non-recycled materials, and the situation is very similar to the recycling of plastics. Today, recycled fibres can be used, for example, as reinforcement in concrete structures. Another trend for the future may be the use of recycled carbon fibres as body parts on cars. Carbon fibres have been used in cars for a long time both in the interior and exterior due to their lighter weight and their distinctive appearance. In the more distant future, it can be expected that a high emphasis will already be placed on the recoverability and usability of materials at the end of a flying career in the development of new generations of aircraft. Manufacturers could opt for materials that are more easily recyclable. Such an approach could be key in addressing current recycling issues such as the quality of materials and the economic efficiency of the process. The activity of the current giants in the transport aircraft market, Boeing and Airbus, has already been described and is expected to grow further in the future.

4.3. Analysis of the current state of aircraft recycling in North America and Europe

When comparing aircraft recycling, the focus will be on the regions of Europe and North America, given their dominant position in the aircraft recycling industry. In the future, with the further development of air transport, we can expect a wider involvement of companies based in powerful Asian economies such as India, Japan, South Korea or China. The latter has considerable potential, not only in terms of the number of aircraft operated and the workforce, but also thanks to its domestic transport aircraft programme, which can be expected to expand considerably once development problems have been overcome.

4.3.1. Locations

Natural conditions are one of the important factors primarily in storage and dismantling, but also in disassembly. The aim is to keep the humidity and the salt content of the air as low as possible in order to reduce the formation of corrosion. In this respect, the United States has a clear advantage, thanks to the dry desert areas in the south-west of the country, such as the states of Arizona and California. Western Europe, where the entire European aircraft recycling system is concentrated, is characterised by a wetter climate thanks to the Gulf Stream. In this respect, Spain has the most ideal conditions in the region.

Indeed, in the United States, the greater part of the facilities are located at airports in these areas. In Arizona there is the aforementioned Davis-Monthan military base, as well as Phoenix Airport, Kingman Airport and Marana Airport. Compared to the rest of the world, this is a significant concentration of these specialised facilities in a relatively small area, which is both an indication of ideal conditions and of an established and proven system. In California, there are San Bernardino, Mojave and Victorville airports. Las Vegas Airport in Nevada and Roswell Airport in New Mexico are also located in these convenient conditions. In the state of Texas, in the south of the country, there is Hondo Airport. A relatively large part of the industry, is located in the state of Florida in the south-east of the country which has the less suitable conditions,. The level of precipitation is relatively high, and Florida is also a peninsula, so the small distance from the sea guarantees a higher level of salt in the air. In addition, the area is one of those with a higher risk of hurricanes. Although these can be predicted fairly well, the problem lies in the fact that aircraft that are unable to fly cannot be evacuated in time. The choice of this location can probably be justified by the large number of aircraft operating in the area, which the companies want to satisfy. Airports in the area include Miami, Fort Lauderdale and Wellington. North of Florida in the state of Arkansas are the Blytheville and Stuttgart airports, and there is a larger facility at the Memphis, Tennessee airport. Although Canada is the largest country in the North American region by area, the challenging natural conditions, the short distance from southern Canada where the majority of the population is concentrated to the US have meant that there is a significantly smaller market for aircraft recycling in the country. The main centre is located at the Montreal airport.

As mentioned, Spain has the most suitable conditions in Europe, with Zaragoza, Valencia, Teruel and Madrid airports, used as dismantling facilities are located. However, the United Kingdom ranks first in terms of the number of companies and facilities in the area. As an island with high levels of rainfall, it has less suitable conditions. Airfields used include the Cotswold, St Athan, Caerphilly, Birmingham, Norwich or Barry. The remaining European airports are located in Ireland (Dublin), France (Tarbes, Chateauroux), the Netherlands (Enschede) and Germany (Hamburg).

4.3.2. Existing companies

There are dozens of companies in both regions involved in the handling of scrapped aircraft, whether in the form of dismantling, disassembly or the sale of spare parts. Each usually has a large area allowing the aircraft to be parked for long periods at one of the less frequented airports, staff and the necessary equipment; if the company disassembly and then sells certified parts, it must have suitable storage facilities. Most of these companies are located in two countries, namely the United States of America and the United Kingdom. For example, Kingman Aviation Parts (disassembly and parts sales) and Kingman Airline Services (MRO, disassembly) are located at Kingman Airport, Ascent Aviation Services (MRO, both disassembly and teardown), Jet Yard Solutions (storage, disassembly and teardown and recycling) are located at Marana Airport in Arizona. In California, First Class MRO (storage, disassembly), Aircraft Recycling Corporation, and ComAv Technical Services (both disassembly, recycling) are located at the Victorville Airport. The Las Vegas airport in Nevada is home to Scroggins Aviation, which, in addition to its traditional activities of storage and dismantling, also provides props for the film industry and benefits from its convenient location. General Airframe Support (both aircraft and powerplant storage and disassembly) is based at Roswell Airport in New Mexico.Hondo Aerospace and the propulsion-only firms BP Aerospace and Conescus Aerospace are also based in Texas. Others are GA Telesis at the Fort Lauderdale airport and AerSale, which is one of the largest firms in the industry. Both are located in the state of Florida and are MRO organizations, but are also involved in disassembly and parts sales. ADI- Aircraft Demolition and Recycling at Wellington Airport (disassembly and recycling) and MD-Turbines in Miami, which is a powerplant disassembly company, are also based here. Blytheville and Stuttgart airports in Arkansas are home to Aviation Repair Technologies (MRO, dismantling storage) and Cavu Aerospace (maintenance, both dismantling and disassembly), respectively. In Canada, Aerocycle, based at the Montreal airport, is the only Canadian company with accreditation from both AFRA and ASA. However, a local aircraft manufacturer, Bombardier, is also involved in disassembly and recycling.

In Spain, at Zaragoza Airport, there is a company called Aviation International Recycling, which dismantles and recycles aircraft. Others are Jet Aircraft Services in Madrid, which is an MRO organisation, also offering both dismantling and recycling services, MAGMA in Valencia, which does not have a narrow specialism in aircraft directly but is focused on the wider industry. Teruel Airport is the largest aircraft storage facility in Europe, some of which is dismantled and recycled here. It is operated by Tarmac Aerosave. In the UK there is Air Salvage International (Cotswold Airport), which dismantles, disassembles and recycles aircraft; eCube Solutions at St Athan Airport in Wales, which disassembles, disassembles and recycles aircraft; AerFin at Caerphilly Airport, which is in the leasing business but also disassembles engines; and STS Aviation Services UK at Birmingham Airport, whose portfolio includes dismantling, disassembly and recycling, Orange Aero Limited, which disassembles and recycles power units, KLM UK Engineering, which is a maintenance organisation at Norwich Airport, where it also disassembles, dismantles and recycles aircraft, or GJD Services at Barry Airport (disassembly, disassembly and recycling of both aircraft and engines). In neighbouring Ireland, EirTrade Aviation Ireland Limited is based at Dublin Airport and dismantles and disassembles aircraft. It is best known for its scrapping of Air France's A380 aircraft. In France, there are Tarmac Aerosave at Tarbes airport, which also operates in Teruel in Spain, and Vallair in Chateauroux (a company with a wide range of activities, including dismantling and recycling). There is also Aircraft End-of-Life Solutions, described above, in Enschede, the Netherlands, and More Aero (dismantling and recycling) in Hamburg, Germany.

4.3.3. _Qualitative and environmental factors_

A number of factors must be taken into account when assessing quality and ecology. The main ones in this case include legislation issued by both aviation authorities and government regulations that affect the wider industry. First and foremost is the ICAO, which brings together all the independent states of the world, and so from its point of view, standards should not differ. Its jurisdiction in the subject is primarily concerned with the use of spare parts, largely in general terms. In the area of maintenance, national or regional aviation authorities have more competence. In the territories compared, three regional aviation authorities have authority, namely the European EASA, the US FAA and the Canadian TCCA. As already mentioned, their authority extends almost exclusively to the process of dismantling and subsequent handling of parts. In Europe this is mainly Part 145, its equivalent in America is Code of Federal Regulations (CFR) 25. Based on bilateral agreements that have been concluded between the three entities, EASA, for example, recognises procedures certified by the FAA and TCCA and vice versa. This applies to routine maintenance as well as to disassembly, repair and any subsequent recertification of used parts, which, in addition to greatly simplifying bureaucratic procedures in practice, also points to similar quality and safety standards in these processes. This contributes to the high quality and transparency of the extracted parts, which are more affordable compared to new production parts. At the same time, U.S. maintenance organizations can directly obtain Part 145 certification from EASA, further simplifying the parts re-export process considerably. As for the subsequent dismantle and recycling process, these are currently not under aeronautical oversight, but under environmental and ecological authorities. In view of this, they may differ not only in terms of Europe-America regions, but also within a single country. They may vary depending on the population density, emission and noise standards in the area. In general, laws in this respect are stricter in the European Union than in the USA, where in some regions such facilities have the support of local authorities due to the fact that they are among the valued employment providers in sparsely populated areas. The government's favourable policy on importing aircraft from abroad has further contributed to the development of the local aircraft recycling industry. In terms of the quality of materials recovered in dismantling and recycling, the situation can also be complex, even though essentially the two most developed regions in the industry are being compared. In fact, there are no regulations in force in this respect yet, apart from legislation on the handling and disposal of hazardous substances. In current recycling, the aim is to find a compromise between the quality of the material and the resources needed to extract it. Therefore, the decision is essentially up to the individual company or the buyers of the recovered material. Certain voluntary quality standards in this area are set out in the AFRA Best Management Practices document. Although this is an initiative of the American Boeing company, it brings together companies from several regions of the world.

4.3.4. _Summary_

The North American and European regions are currently leading the industry and setting the standard for other regions. The leader among countries is the United States followed by the United Kingdom. Companies from these regions represent the best options for aircraft operators who do not have their own MRO organisation. As these are, without exception, advanced economies, the cost of the work itself may be higher here than elsewhere, but the result is the reliability and quality of certified and proven parts, which can save considerable money while contributing to flight safety. Minimal environmental impact is guaranteed when disassembled and then recycled according to AFRA procedures. This could be further reduced by the development of binding legislation on aircraft recycling.

5. CONCLUSION

The aim of the article was to evaluate the current state of the processes that the decommissioned aircraft is going through and to suggest possible improvements. Although aircraft are amongst the most expensive products to manufacture and one would expect that the effort to recover and reuse the material should be as old as aviation itself, this is not the case. It is only in the new millennium that it has been discussed at an industrial level.

The main obstacle that has made the possibility of recycling ignored for a long time is the quality of the materials. The problem is that economically viable separation of individual layers of materials at the required quality persists to the present day. A new challenge in terms of recycling is posed by the increasing share of new materials, such as mainly composites. Although these have been in use for some time, due to their low share to date, coupled with a general lack of interest in aircraft recycling in general, the issue of their reuse has not been addressed. A further complication is the absence of regulations in the area of disassembly, which nowadays prevents the use of larger structural units, and in the area of recycling, where operators are not forced to recover the materials used to build the aircraft.

Although the industry is currently recovering from the effects of the COVID-19 pandemic, it is expected to grow and develop again. At the same time, its environmental impact, which is not insignificant, needs to be comprehensively eliminated.

Greater use of mechanisation in aircraft recycling would contribute to a more efficient selection of the materials of current alloys. Intensive research into increasingly efficient recycling methods will be key to the reuse of materials that could eventually be reused in aircraft manufacture. Manufacturers could also make a major contribution to this, starting at the design and development stage itself. If binding legislation were to be adopted requiring aircraft owners to dismantle and recycle their aircraft, it would be possible to proceed in a similar way to the automotive industry. A proactive approach to recycling by Western aircraft manufacturers is already evident and could be further extended, for example by providing benefits to operators who take a proactive and responsible approach to recycling. Based on the initiative of the aircraft manufacturers themselves, aircraft recycling is a relatively prestigious industry, which is generally located only in the most advanced countries with available technologies and facilities. The United States currently has the largest market presence, followed by the United Kingdom.

It is safe to say that the future of aircraft recycling will be positive, despite the current crises. Even the current state of affairs, with energy and material costs rising significantly, will have a positive impact on this, which will not only affect the environment, but will also contribute to the creation of new jobs and could further improve the image of aviation in the eyes of the general public, as well as environmentalists, who have long been critical of the negative impact of aviation on the environment.

REFERENCES

[1] INTERNATIONAL AIR TRANSPORT ASSOCIATION. 2018. Best Industry Practices for Aircraft Decomissioning (BIPAD) 1st Edition. [online]. 2018. 101p.[cit. 2022-03-22]. Available on the internet: https://www.scribd.com/document/420730740/BIPAD . ISBN: 978-92-9229-827-2.

[2] INTERNATIONAL AIR TRANSPORT ASSOCIATION. 2020. Guidance for Managing Aircraft Airworthiness for Operations During and Post Pandemic. [online]. 2020. Available on the internet: https://www.iata.org/contentassets/d0e499e4b2824d4d867a8e07800b14bd/iata-guidance-managing-aircraft-airworthiness-during-post-pandemic.pdf.

[3] SGI AVIATION. 2018. Aircraft Decomissioning Study. [online]. 2018. 80 p. [cit. 2022-03-28]. Available on the internet: https://www.sgiaviation.com/wp-content/uploads/2020/03/IATA_Aircraft_Decommissioning_Study_May-2018.pdf .

[4] AUSTRALIAN TRANSPORT SAFETY BUREAU. 2007. How Old is Too Old? The impact of ageing aicraft on aviation safety. [online]. 2007, 78 p. [cit. 2022-04-08]. Available on the internet: https://www.atsb.gov.au/media/29959/b20050205.pdf. ISBN: 1-921-164-39-5.

[5] RIBEIRO, J. S. - GOMES. J. O. 2015. Proposed framework for End-of-Life aircraft recycling. In Procedia CIRP Volume 26. [online]. 2015, vol. 26, p. 311-316. [cit. 2022-03-22]. Available on the internet: https://www.sciencedirect.com/science/article/pii/S2212827114008610 .

[6] ASMATULU, E. - OVERCASH, M. - TWOMEY, J. 2013. Recycling of Aircraft: State of the Art in 2011. In Journal of Industrial Engineering. [online]. 2013, vol. 2013, 8 p. [cit. 2022-03-23]. Available on the internet: https://www.hindawi.com/journals/jie/2013/960581/ .

[7] SZABO, S. - KOBLEN, I. - VAJDOVÁ, I. 2015. Aviation Tehnology Life Cycle Stages. In eXclusive e- JOUNAL. [online]. 2015, 8 p. [cit. 2022-04-10]. Available on the internet: https://www.researchgate.net/publication/306165621_Aviation_Technology_Life_Cycle_Stages. ISSN: 1339-4509.

[8] SABAGHI, M. - CAI, Y. - MASCLE, CH. - BAPTISTE, P. 2015. Sustainability assessment of dismantling strategies for end-of-life aircraft recycling. In Resources, Conservation and Recycling. [online]. 2015, vol.102. p. 163-169. [cit. 2022-03-26]. Available on the internet: https://www.sciencedirect.com/science/article/pii/S0921344915300653.

[9] ZHAO, D. - GUO, Z. - XUE, J. 2020. Research on Scrap Recycling of Retired Civil Aircraft. In IOP Conference Series: Earth and Environmental Science [online]. 2020, vol. 657. 10 p. [cit 2022-03-26]. Available on the internet: https://iopscience.iop.org/article/10.1088/1755-1315/657/1/012062/pdf.

[10] WONG, K. - RUDD, CH. - PICKERING, S. - LIU, X. 2017. Composites recycling solutions for the aviation industry. In Science China Technological Sciences. [online]. 2017, vol. 60, 10 p. [cit. 2022-03-26]. Available on the internet: https://www.researchgate.net/publication/317973117_Composites_recycling_solutions_for_the_aviation_industry. ISSN: 1674-7321.

[11] KHAN, W. - SOLTANI, S. - ASMATULU, E. – ASMATULU, R. 2013. Aircraft recycling: A review of current issues and perspectives. [online]. Wichita. 2013, 11 p. [cit. 2022-03-26]. Available on the internet: https://www.researchgate.net/publication/289031934_A

ircraft_recycling_A_review_of_current_issues_and_perspectives.

[12] KRAUKLIS, A. – KARL, CH. – GAGANI, A. – JORGENSSEN, J. 2021. Composite Material Recycling Technology—State-of-the-Artand Sustainable Development for the 2020s. [online]. 2021, 33 p. [cit. 2022-04-01]. Available on the internet: https://www.researchgate.net/publication/348529249_Composite_Material_Recycling_Technology-State-of-the-Art_and_Sustainable_Development_for_the_2020s.

[13] MAAß, S. 2020. Aircraft Recycling – A Literature Review. [online]. Hamburg. 2020, 61 p. [cit. 2022-04-07 Available on the internet: https://www.fzt.haw-hamburg.de/pers/Scholz/arbeiten/TextMaass.pdf.

[14] BRUIJNS, E. – GREEUW, M. 2017. AMARG je víc než jen hřbitov. In Letectví + Kosmonautika. 2017, vol. 3, p.50-55. ISSN: 0024-1156

[15] LAKE. J. 2019. Keeping the legacy alive- part one: US operators. In Air Forces Monthly. 2019, vol. 4, p. 50-55.

[16] INTERNATIONAL CIVIL AVIATION ORGANIZATION. 1969. Annex 6 to the Convention on International Civil Aviation-Operation of Aircraft. [online] Montreal. 2018, 10th edition, 188 p. [cit. 2022-04-14]. Available on the internet: http://www.icscc.org.cn/upload/file/20210603/20210603132536_27477.pdf.

[17] INTERNATIONAL CIVIL AVIATION ORGANIZATION. 2005. Annex 8 to the Convention on International Civil Aviation-Airworthiness of Aircraft. [online] Montreal. 2005, 5th edition, 124 p. [cit. 2022-04-14]. Available on the internet: https://aviation-is.better-than.tv/icaodocs/Annex%208%20-%20Airworthiness%20of%20Aircraft/Annex%2008,%2010%20edition.pdf.

[18] EUROPEAN AVIATION SAFETY AGENCY. 2015. Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex II (PART-145) to Regulation (EU) No 1321/2014. [online]. 2015, 2nd edition, 82 p. [cit. 2022-04-13]. Available on the internet: https://www.easa.europa.eu/sites/default/files/dfu/Annex%20II%20to%20Decision%202015-029-R%20-%20%28AMC-GM%20Part-145%29.pdf.

[19] EUROPEAN AVIATION SAFETY AGENCY. 2015. Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex I (PART-M) toRegulation (EU) No 1321/2014. [online]. 2015, 2nd edition, 253 p. [cit. 2022-04-13 Available on the internet: https://www.easa.europa.eu/downloads/20260/en.

[20] ELSAYED, A. – ROETGER, T. – BANN, A. 2019. Best Practices and Standards in Aircraft End-of-Life and Recycling. In Destination Green. [online]. 2019, p. 279-284. [cit. 2022-04-14]. Available on the internet: https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg279-284.pdf.

[21] Meet the Israel Air Force unit that frankensteined a totaled F-15 [online]. Available on the internet: https://www.defensenews.com/air/2017/05/15/meet-the-israel-air-force-unit-that-frankensteined-a-totaled-f-15/ (cited 2022-04-07)

[22] Fighter Jet Crashes in Forest [online]. Available on the internet: https://yle.fi/news/3-5495390 (cited 2022-04-07)

[23] Aircraft Recycling Market Report [online]. Available on the internet: https://www.gminsights.com/industry-analysis/aircraft-recycling-market (cited 2022-04-20)

[24] Commercial aircraft disassembly, dismantling & recycling market size [online]. Available on the internet: https://www.fortunebusinessinsights.com/commercial-aircraft-disassembly-dismantling-and-recycling-market-103584 (cited 2022-04-20)

[25] We Finally Know How Many F-22s Were Left Behind At Tyndall AFB During Hurricane Michael [online]. Available on the internet: https://www.thedrive.com/the-war-zone/24442/we-finally-know-how-many-f-22s-were-left-behind-at-tyndall-afb-during-hurricane-michael (cited 2022-04-20)

[26] AFRA Members [online]. Available on the internet: https://afraassociation.org/accreditation/directory-of-accredited-companies/ (cited 2022-04-20)

[27] Dismantling and recycling [online]. Available on the internet: https://www.myairtrade.com/resources/dismantling (cited 2022-04-20)

[28] BUGAJ, M., NOVÁK, A. 2010. Všeobecné znalosti o lietadle : drak a systémy, elektrický systém. - 1. vyd. - Žilina : Žilinská univerzita, 2004. - 247 s. - ISBN 80-8070-210-1.

[29] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

[30] BUGAJ, M., URMINSKÝ, T., ROSTÁŠ, J., PECHO, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40. ISSN 23521457.