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Circularity and Sustainability in Aerospace: The Case of Spacecraft Materials

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Abstract

Sustainability and the need for material circularity are the main challenges the industries are facing and not only the ones on the ground. [1][2]. Indeed, the aerospace industries are currently investigating solutions to implement sustainability and circularity [1][3]. The aviation sector implemented concepts related to the refurbishment of engines, aircraft parts, and the repurposing of whole planes from passenger transport to cargo and freight logistics. While the space industry still needs to develop missing technologies to enable circular material flows or to reuse spacecraft materials in space [1].
The space industry may be late regarding the implementation of sustainability compared to other sectors. Nevertheless, it can certainly learn from other sectors, particularly from its closest sibling: the aviation industry.
The aviation industry is ahead of the space industry regarding sustainability and circularity [4][5][6], even though concepts such as reusing, repairing, and recycling are already fundamental to crewed space missions and some special missions such as the Hubble Space Telescope [7]. It will become even more crucial when humanity will explore deep space going farther and farther away from Earth, from its resources, and a potential rescue mission [1].
Therefore, to succeed in the implementation of circularity in space, this paper aims to investigate previous technology spin-offs, to understand and analyze how the aviation and the space industry learned from each other to present the best practices and extract the best practices to succeed in the implementation of circularity in space by identifying what can be transferred from aviation.

Keywords: Technology transfer, Space, Aviation, Circularity

1. Introduction

Sustainability and circularity are the main challenges the industries are facing and not only the ones on the ground [1][2]. Indeed, the aerospace industries are currently investigating solutions to implement sustainability and circularity [1][3][31]. The aviation sector implemented concepts related to the refurbishment of engines, aircraft parts, and the repurposing of whole planes from passenger transport to cargo and freight logistics. While the space industry still needs to develop missing technologies to enable circular material flows or to reuse spacecraft materials in space [1][31].
The space industry may be late regarding the implementation of sustainability compared to other sectors. Nevertheless, it can certainly learn from them, particularly from its closest sibling: the aviation industry.
The aviation industry is ahead of the space industry regarding sustainability and circularity [4][5][6], even though concepts such as reusing, repairing, and recycling are already fundamental to crewed space missions and some special missions such as the Hubble Space Telescope [7]. It will become even more crucial when humanity will explore deep space going farther and farther away from Earth, from its resources, and a potential rescue mission [1].
Therefore, to succeed in the implementation of circularity in space, this paper aims to investigate previous technology spin-offs and spin-in, to understand and analyze how the aviation and the space industry learned from each other and

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to present the best practices, and to extract those to succeed the implementation of circularity in space by identifying what can be transferred from aviation. This paper describes the different technology transfers along with examples of those transfers between the space and aviation industries as the GPS, and de-icing systems. Then, the sustainability challenges of those industries are described along with potential technology transfer that could help to investigate solutions such as the hydrogen propulsion or action line for circularity.

2. Spin-off and spin-in technology transfers

2.1. Spin-off technology transfer definition

A technology is developed to assess a specific need, but it may respond to multiple ones [8]. Spin-off technology is a technology originally developed for an industry need that has been transferred to another industry to assess other uses [8]. Discussion on the definition occurs to include the resources provided by the parent organization or to limit the definition to specific resource transfers [54]. An example of spin-off technology transfer is the printing press of Gutenberg. Indeed, the technologies used to create the mass printing process were used for different applications. At the time, the press was used in viticulture, the alloys and molds were used in smithery, and the sorts were already existing in Asia [9].
For the space industry a spin-off, or a technology transfer, is a technology developed for a space mission that is transferred to another industry. A well-known example is the seismic dampers derived from the shock absorber save structure used for the service structure of the space shuttle.

For this paper, the space industry spin-off definition is used.

2.2. Spin-in technology transfer definition

A spin-in technology transfer is the opposite of a spin-off technology, it is the technologies acquired by a company or an industry domain from another domain [10]. The technologies transferred are usually considered important for the growth of the industry [55]. Thus, the shock absorber save structure developed by NASA from the previous example is a spin-in technology for the building industry.
From the point of view of space, a technology acquired by the space industry from another industry is a spin-in technology. This definition is used in this paper.

2.3. Spin-out technology transfers definition

A spin-out management is the separation of a new or existing part of a parent organization to independently develop related or unrelated activities by profiting from the parent's asset [11]. This process requires a transfer of technologies from the parent organization to the new business along with people, assets, intellectual properties, customers, or whole business units [12]. The goals of this process are to commercialize research and development results that have not been successful in the parent organization's business units, to externalize activities that are no longer core, to develop, and where their cost can be reduced if they are produced for other organizations [10]. Spin-out also permits the development of new competencies, to exploit technologies, and research assets unused in the main activities of the parent organization [55]. Spin-out is often replaced by spin-offs in the literature [54].

2.4. Spin-along technology transfers definition

The spin-along technology transfer is a mix between spin-in and spin-out activities: it permits to commercialized innovation results that did not fit the business units of the parent by creating a spin-out company that remains outside the parent organization not hindered by it but is still under the parent control that provides protection [10][13]. Since the parent organization maintains dominant equity in the new company it can be reintegrated, or "spun in" [13].

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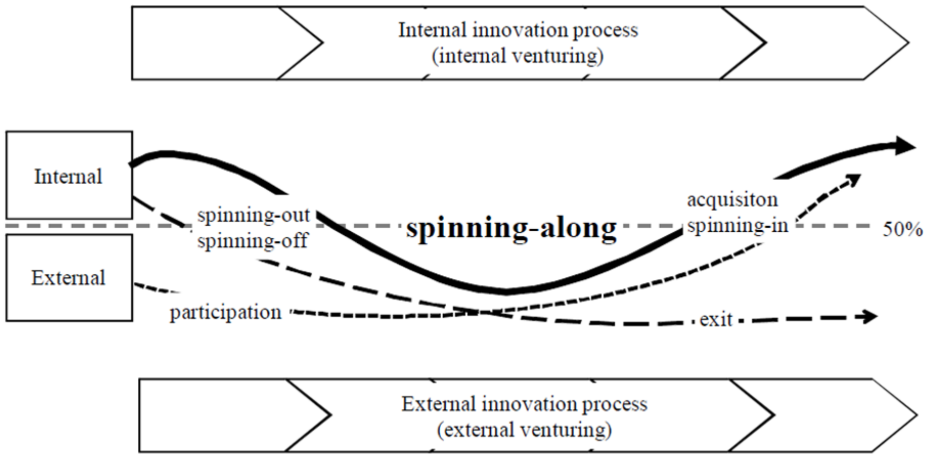

Figure 1: The spin-along process [13]

3. Example of Spin-off and Spin-in technology transfers

3.1. From Space to Aviation

3.1.1. Spin-off: Global Positioning System

3.1.1.1. History of GPS

The idea of GPS started before the beginning of the space race with the development of a three-dimensional position-finding system based on the time difference of arrival of radio signals by Dr. Ivan Getting in 1951. Nevertheless, in 1957, Sputnik permits to confirm that, if a satellite position was known, the position of a receiver on Earth could be determined [14]. The development of space missions such as the Timation satellites gave the technologies necessary for GPS.

In 1973, the then-colonel Dr. Brad Parkinson at the United States Air Force Space and Missile Systems Organization leads an office to develop the GPS architecture and initiated the development of the first satellites called the NAVSTAR-Global Positioning System [14]. The first ten development satellites were launched between 1978 and 1985 along with the development of the initial ground segment that would provide the critical uploads to the satellites [14].

At first, the GPS was developed for military use but following the downing of Korean Airlines Flight 007 by USRR after it accidentally crossed the Soviet Union territory in 1983, US President Ronald Reagan decided to open the GPS to civil once the system became operational [15].

Therefore when, the constellation of 24 satellites was successfully launched Between 1989 and 1994 and declared fully operational, in 1995 [14], a signal was dedicated to civilian uses [14]. The new generation of GPS satellite, called Block, bring new improvement at each iteration. In 2010 the first Block IIF satellite added a third signal to help ensure the availability of GPS to civil aeronautical and search-and-rescue users [14].

3.1.1.2. GPS and Aviation

In 1994, the Federal Aviation Administration announces GPS as the first navigation system approved for use as a stand-alone navigation aid for all phases of flight through a non-precision approach [15]. At the time most of the GPS sets were developed for military applications and time transfers and geodetic applications [16]. For aviation, all the avionics need to be certified by the FAA, with the Technical Standard Order and the supplemental Type Certificate, to be used but at this time no specifications existed for GPS sets [16]. Nonetheless, some GPS sets were designed according to the applicable requirements of the ARINC and RICA as LTN-700 [16].

The International Civil Aviation Organization i.e., ICAO, developed the Required Navigation Performance a set of specifications that permit the operation of aircraft along a precise flight path with a high level of accuracy and the ability to determine aircraft position with both accuracy and integrity [17][18]. It is now under the Performance Based Navigation since 2012, it ensures the global standardization of RNAV and RNP specifications and limits the

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proliferation of navigation specifications in use worldwide [19][20]. The GPS increased aviation's safety, efficiency, and profitability [14].

3.1.2. Spin-out: "Deicing" and anti-icing systems

Ice development on the aircraft surface is dangerous; its presences increase drag and reduce lift [21]. The NASA Glenn Center is investigating the development of material for extreme condition applications and has an Icing branch that studies the growth of ice on aircraft, the effect it could have during flight, and systems to protect aircraft from ice [21].

3.1.2.1. Thermoelectric system: Thermawing

The Thermawing system development started in 1999, NASA Glenn Center worked in collaboration with Kelly Aerospace via the Small Business Innovation Research program, i.e., SBIR [21][22]. It was developed based on the graphene foil heating element technology used for decades for high-temperature heating applications [21][22]. Kelly Aerospace acquired Northcoast Technologies Ltd., a firm that had similarly done graphite foil heating elements [21]. Since the major customer was Cessna, the system was designed for Cessna 350, 400, and Columbia 350 [21][22]. At the time, single-engine aircraft did not have access to de-icing systems to fly safely through ice encounters [21]. The deicing system uses a flexible, electrically conductive graphite foil, that can instantaneously rise the temperature when requested [21]. The thin laminate system, which contains the flexible, expanded graphite foil that serves as an electrical and heat conducting layer, is applied like tape to the surface of the aircraft where ice formation is critical [21].
The system is composed of six heaters, three heaters control modules, one main electronic controller, and a 7500-Watt alternator to deice the aircraft [22]. During the de-icing cycle, the voltage is increased, and the heater is pulsed to temperatures above freezing [22]. The rise in temperature permits the ice to detach from the heater surface, the ice is removed by the aerodynamic forces [22].
The collaboration resulted in several outcomes as the certification and the integration of a thermoelectric deicing system, a DC-powered air conditioning for single-engine aircraft, and high-output alternators to run them both [21].
The Cessna 400 aircraft are not production since 2018, but the models are still popular among the private pilot community. Thus, the Thermawing technology has been adapted to other applications as a deicing system for wind turbines [23].

3.1.2.2. Electro-Mechanical Expulsion Deicing System EMEDS

As the Thermawing, the EMEDS system is the result of an SBIR collaboration between NASA Glenn and Cox&Company. EMEDS combines an anti-icing system with a mechanical deicer developed by NASA called the Electro-Mechanical Expulsion Deicing System i.e., EMEDS [24]. This combination permits to reduce the aerodynamical losses due to the deicing system [24]. The EMEDS is composed of an electronic Deicing Control Unit, an Energy Storage Bank, and a Leading-Edge Assembly, consisting of actuators mounted in an airfoil-shaped structure with a metal or composite erosion shield [25]. The actuators receive a high current electrical pulse for a millisecond in controlled time intervals to generate opposing electromagnetic fields that cause the actuators to change shape rapidly [25]. This change of shape will cause the erosion shield to flex and vibrate at high frequencies resulting in acceleration-based debonding of accumulated ice on the erosion shield [25].

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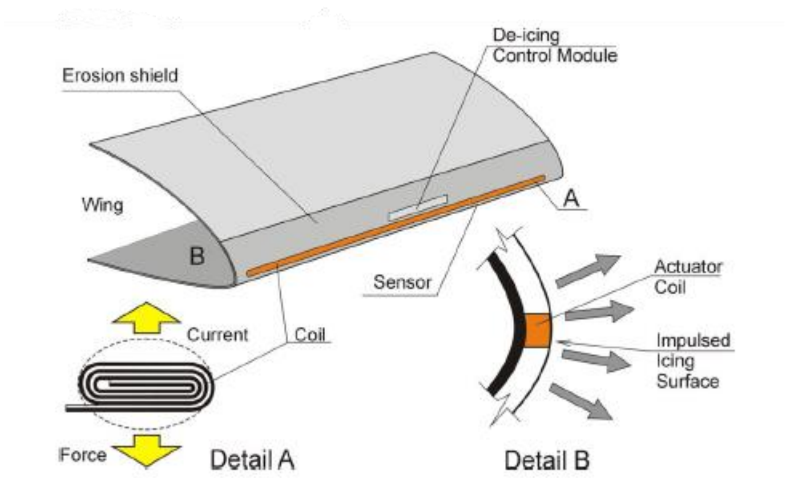

Figure 2: EMDES Credit Cox&Company [51]

The EMEDS is still used by in-service aircraft models such as the U.S. Navy P-8 Poseidon or the Cessna Citation Longitude. Cox&Company used the EMEDS technology to create new deicing technologies such as the Thermo-Mechanical Expulsion Deicing System and a hybrid system of EMEDS and Electro-Thermal Hybrid used by different aircraft models [25].

3.1.3. Spin in: Integrated Modular Avionics IMA

3.1.3.1. Integrated Modular Avionics in Aviation

Integrated Modular Avionics i.e., IMA, has been developed by the aviation industry to assess the growth of functionalities required by aircraft [26]. Indeed, the IMA replaced the federated architecture mainly used since the beginning of aviation, within the federated architecture each function of avionics is a self-contained black box, Line Replaceable Unit, i.e., LRU, that includes every resource needed by the functionality [26]. One function means one LRU which with the growth of functionality cause an issue of mass, power, and volume [26]. IMA identifies the sets of common resources shared by most functionalities i.e., the resources replicated in all LRUs in federated architecture (Fig 3) [26]. The application sharing the same platform are virtually separated, the separation is provided by partitioning the common resources and assigning those partitioned resources to an application [26]. Moreover, the applications can only use the processor for a limited time and are restrained in memory access [26]. Thus, the applications are separated in space and time which means that their performance will not be affected by the sharing of computing resources and faults will not be propagated [26].

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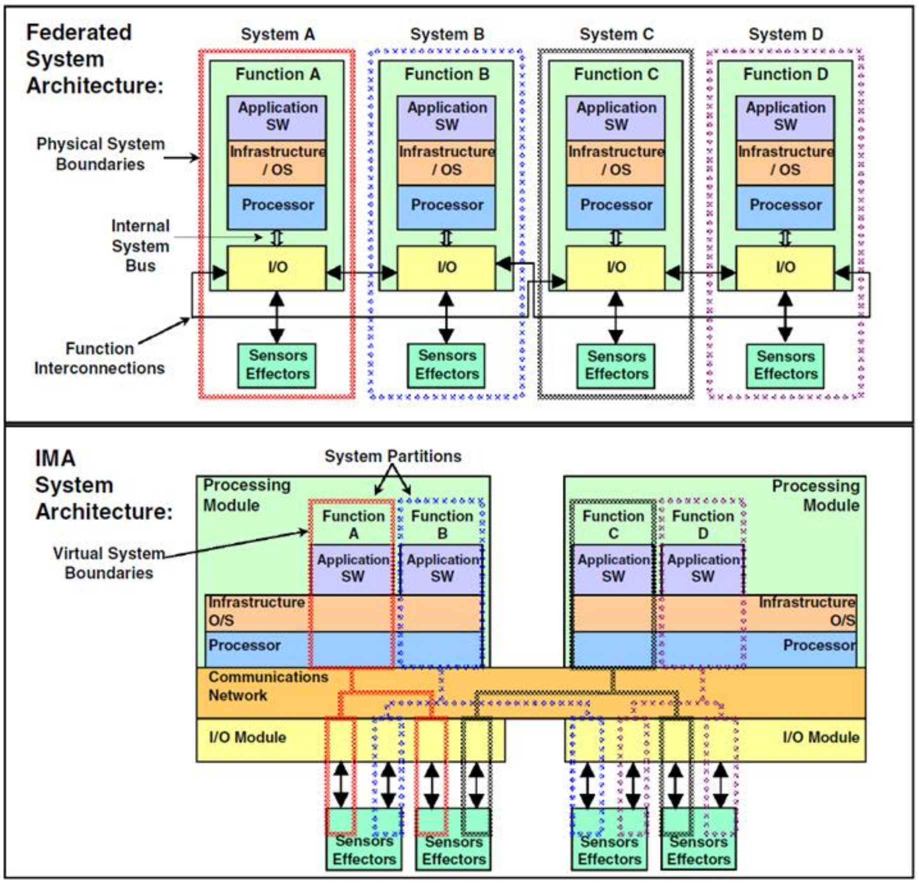

Figure 3: Federated and IMA architectures [27]

IMA was used in A380, and Boeing 787, Airbus and Boeing's programs reported savings in terms of mass, power, and volume of 25%, 50%, and 60% respectively [26]. Today, it is still used on A350, A400M, A220, Boeing 777, and the Rafale.

3.1.3.1. Integrated Modular Avionics for Space IMA-SP

Integrated Modular Avionics i.e., IMA architecture rises the interest of the space industry which is facing a growth of mission functions embedded in the onboard software [28]. IMA is expected to manage this growth and save on mass, volume, and power requirements that are even more crucial for space missions [28]. Moreover, space avionics are not as standardized as aviation avionics [26].

Nonetheless, to successfully implement IMA to space it is crucial to understand the differences between the two industries [26]. ESA developed a guide for the development of the IMA-SP platform [26]. The first one is to maintain the Real Time Operating System: RTEMS i.e., Real-Time Executive for Multiprocessor Systems which is free and open source [26]. It is used for most ESA missions which means many software implementations are using RTEMS [26]. Thus, maintaining RTEMS in the IMA-SP platform will prevent their reimplementation [26]. Moreover, RTEMS presents aspects that are already fulfilling the ARINC 653 standard that defines the interface between software applications and underlying operating systems [26]. Nevertheless, time and space partitioning must be applied in the RTEMS [26]. ESA defined a two levels software executive composed of a software hypervisor to segregate computing resources between partitions [26]. Three hypervisors are investigated by ESA: XtratuM, AIR, and PikeOS [26].

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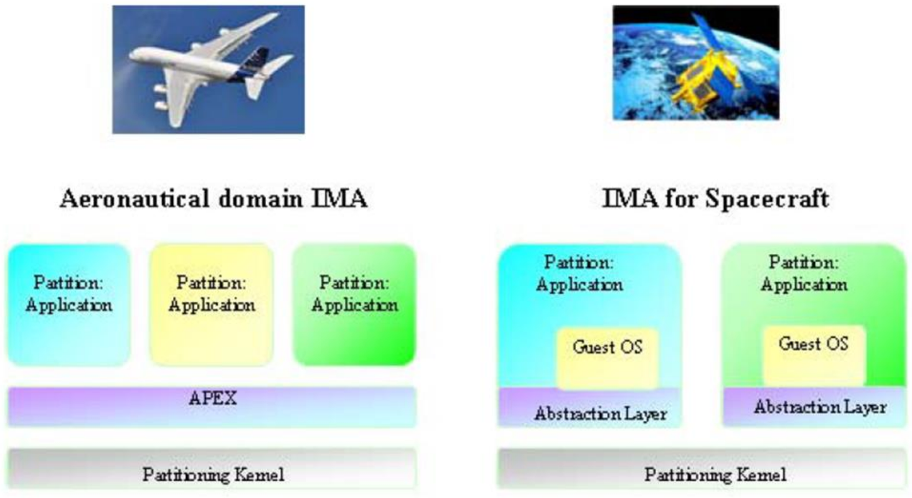

Figure 4: Comparison between aeronautical and space time and space partitioned platforms [26]

Astrium, now AIRBUS, developed a demonstrator based on AS250 avionics architecture [29]. AS250 is used for Earth Observation in LEO [29]. Its corresponding test bench is based on the Numerical Software Validation Facility which includes simulated hardware onboard the computer where the software under test is running, simulated communication links, simulated avionics equipment resources, and test execution control services [29]. The study tested two different scenarios: a specific test in an open loop and a global test in a closed loop [29].

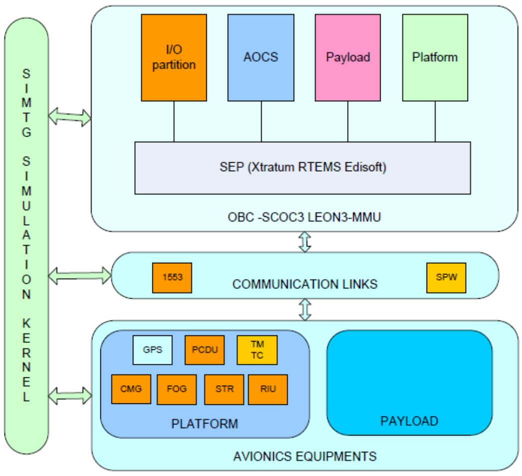

Figure 5: AS250 partitioned architecture [29]

In 2021, the Czech Republic within the general support technology program of ESA to build a framework to develop IMA-SP and to implement and integrate it into a space mission hosting a payload to demonstrate the feasibility of the concept and to investigate the multi-core processors regarding IMA-SP [30].

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4. Sustainability and Circularity the new challenges for Aerospace

4.1. Sustainability for Aviation

Sustainability concerns all industry sectors, including the aerospace industries. Comparing both is relevant since the aviation sector is relevant since it shares many aspects with the space industry, and they are used to working together. Aviation sustainable objectives are to reduce carbon dioxide, i.e., CO2 emission by at least 55% in 2030, and to become a net zero CO2 emission by 2050 [1]. Nonetheless, those objectives only cover parts of the emission of aviation: the non-CO2 emissions such as nitrogen oxides, i.e., NOx and water vapor are not included [2]. Moreover, aviation impact on the environment via noise pollution, and land pollution [2]. Aviation impacts are classified into three categories: air pollution, noise pollution, and land pollution [2]. The aviation industry represents 3.9% of the worldwide CO2 emission and it succeeded to decrease by 24% the amount of fuel burned per passenger between 2005 and 2017 thanks to the improvements in fuel efficiency with new aircraft design new engines and optimization of air traffic [1][4]. However, it is overcompensated by the industry growth [4].

4.2. Sustainability for Space

Regarding the space industry, sustainability only recently arrives on the table of its actors. Despite being an important player in the achievement of sustainable development goals and their targets, those are not fully applicable to space [31]. Space is important for daily life on Earth with GPS or meteorology, and its applications will only increase in the coming years. Thus, space is a part of our environment, our society, and our economy [31]. Space activity must then be sustainable to ensure future missions and human presence in space. Today, sustainability in space mainly focuses on space debris issues such as the collision risk increase or the potential happening of the Kessler effect [31]. Thus, ESA sets the sustainability objective of "zero debris" [32] which can be done by cleaning the debris already in space and including End-of-life strategies in the mission. Of course, being sustainable in space need tools such as Space Situational Awareness, Collision Avoidance, Active Debris Removal, and a spacecraft end-of-life that is either burning in the atmosphere or is putting in a graveyard orbit [32][31].

4.3. Circularity for Aviation

Circularity is considered the next step of sustainability. Aviation is still at the beginning of its implementation. Nonetheless, it presents initiatives to implement concepts for circular aviation. The aim is to assess the demand for sustainable aviation [26] by reducing emissions, waste, and the general impact on the environment without impacting economic growth and limiting passenger and freight transportation [26].

Action lines have been identified. The first ones concern the implementation of the circularity principle at the design and production phases of an aircraft [26] by having a design that extends the durability of the aircraft, choosing materials from cleaner resources, resourcing recycled materials, and decreasing waste during manufacturing [26]. Circularity must also be implemented during the life of the aircraft by encouraging recycling activities on-board or not, the digitalization of reports to manage and record ground operations, reduction of noise, and use of cleaner taxis. The maintenance, repair, and overhaul activities already fit the circularity principle, but research is conducted to optimize aircraft life duration [26]. The use of alternative fuels, less impactful on the environment is also considered an action line for circular aviation [26].

4.4. Circularity for Space

Circularity has only recently appeared on the table of the space industry. Nevertheless, it is necessary if humanity wants to explore space going further away from Earth, by supplying mission and help [31]. Initiatives are appearing, such as the recycling of space debris on the Moon or the reuse of spacecraft materials but they are a minority [31].

A concept to implement circularity in space is the reuse of spacecraft materials [31]. Indeed, Active Debris Removal i.e., ADR, projects often end in the destruction of two spacecraft along with their technologies, their materials, and their investments [31]. Nevertheless, the reuse of spacecraft material requires technologies and knowledge that are still in development such as the capability to capture a spacecraft, knowledge of the materials property's evolution in space, spacecraft design enabling reuse, and the reuse processes [31]. Of course, research domains are also investigating those technologies as ADR for the capture concept or in space manufacturing for the processes [31]. Those missing technologies and knowledge will arrive, and space circularity must foresee the achievement of its requirements to be easily implemented in the future.

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5. Technology transfers to achieve sustainability and circularity

5.1. Potential Spin-off: Hydrogen propulsion

The aviation industry is investigating options to replace the fossil fuel of its aircraft. Three possibilities are inquired: Sustainable aviation fuels, hydrogen propulsion, and electric propulsion [4]. Hydrogen propulsion is one of the solutions investigated to make the industry more sustainable. Hydrogen can be used in two ways: hydrogen combustion and hydrogen fuel cells [35]. Hydrogen combustion consists of burning hydrogen instead of kerosene [34]. This method could achieve a zero-carbon solution, but it still emits NOx and water vapor which are greenhouse gases [34]. A hydrogen fuel cell involves producing electricity from hydrogen and oxygen inputs to power an electric motor that in turn drives a propeller or ducted fan [34]. The key challenges for hydrogen to become a solution for aviation propulsion are the aircraft and engine redesign, the storage of hydrogen, sustainable hydrogen production, the infrastructure, the cost, and the opinion of the clients on hydrogen [34] [35]. For example, the storage of hydrogen must ensure the higher gravimetric energy density of hydrogen and address the issue of its lower volumetric energy density. The liquid state of hydrogen seems to be the best option since it limits the effect of the volumetric energy density compared to the gaseous state. However, it requires a temperature of -253 degrees Celsius to maintain hydrogen in the liquid state and therefore a cooling system that will need energy [34].

A potential spin-off technology transfer can come from rocket propulsion as liquid hydrogen, with liquid oxygen, is used in the space industry as rocket propellant to launch crew and cargo, such as Centaur, shuttles, and Apollo [36]. Hydrogen is a light and powerful propellant since it has the highest specific impulse i.e., the time during which one kilogram of propellant produces the thrust necessary to lift a one-kilogram mass in the earth's gravitational field [37] corresponding to a thrust force of 9.806 65 N, it is 440s for the first stage of Ariane 5 that use liquid dihydrogen and liquid oxygen [38].
Liquid hydrogen must be stored at -253 degree Celsius i.e., its condensing temperature, which requires the tank to be well insulated from all sources of heat, such as air friction or radiant heat from the Sun, to prevent evaporation or boiling of hydrogen [39]. Moreover, when heated the liquid hydrogen extend which can make the tank explode therefore venting is necessary. Furthermore, cryogenic temperatures make the metal more brittle, and liquid hydrogen can leak through the pores of the welding [39].
During the 1960s, the Apollo program developed technologies to store and deliver liquid hydrogen to the rocket stages such as cryogenic piping systems, components, and systems [58][41]. The piping system was reused for the space shuttle [58]. Moreover, a new tank was installed on the launch pad complex 39B for the Artemis mission [41]. The new tank presents new technologies: integrated refrigeration and storage heat exchanger and Glass Bubbles Thermal insulation system [41]. Those technologies permit to achieve of better energy efficiency and full control of cryogenic storage [41].

Figure 6: Space shuttle liquid hydrogen tank Credit NASA

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The space industry used liquid hydrogen as a propellant for over 30 years. Despite, this being well-known in the space community, it is often seen that no technology readiness level exists for hydrogen propulsion in the literature on sustainable fuels for aviation [4]. Lessons could be learned from the Apollo program, the Space Shuttle program, and the Artemis program. The storage technologies could be used adapted for the aviation industry's needs [54] as the higher rate of take-off and landing.

5.2. Potential Spin-in: Circularity Action Lines

As said before the aviation industry has identified action lines to enable circular aviation some of which echo the needs of the space industry. To successfully implement circularity, it must be considered at the beginning of the design phase [33]. Aircraft already have features that facilitate the implementation of circularity [33]. They are designed for long-time service: It is common for operators to transform their passenger aircraft into cargo aircraft to prolong their utilization during an extended life cycle but also to be maintained, repaired, and dismantled [26]. The refurbishing of aircraft is frequent in niche aircraft markets as demonstrated by the company Bushliner Aircraft Remanufacturing [43] that specialized in the restoration of Cessna 180 and 185, models that are not in production anymore but are still popular within the general aviation community [43]. The company goes even further by providing upgrades to such aircraft to extend their operational life [43].

Furthermore, the industry also implements circular processes such as remanufacturing. It is an industrial process where a used product is brought back to its manufacturer or another company [45]. Then, the product is inspected to determine potential malfunctions. It is cleaned and disassembled valuable parts are stored to be reassembled later and the broken ones are sent to a recycling or incineration center [45]. The valuable parts are reprocessed, reassembled, potentially with upgrades, and finally tested to verify if the "like new" product meets the strict requirements: functionality, security, and quality of new products [45]. This process is already implemented in large-scale operations of transport aircraft as demonstrated by the Dutch company AELS i.e., Aircraft End-of-Life Solution [44]. It buys aircraft reaching their end-of-life, disassembles them, stores the valuable parts, recertifies them, and returns them to the market [44]. The company has already disassembled more than 75 aircraft and is active in the implementation of a circular economy within the aircraft industry [44]. Nonetheless, one of the circular aviation action lines is to design aircraft to be circular to improve those processes [33].

The selection of the used materials should also be considered during the early design phase to take into consideration their impact on the environment from the extraction of the raw material to their end-of-life process [33]. Circular aviation should favor the use of recycled materials to limit the extraction of raw materials [33]. Nonetheless, those materials should be approved by the regulation of aviation [33].

Those guideline applications should be investigated for the space industry. To be reused spacecraft must be designed to do so at an early phase of the mission design [31]. Modularity is a crucial design aspect to enable servicing of spacecraft in space [46]. It will be even more important to reuse spacecraft components since they need to be dismantled and processed to be reused. In-space manufacturing should include end-of-life processes such as remanufacturing, reusing, or recycling spacecraft and space debris [31][47][48]. As an example, Creaternity Space Lab is investigating concepts to enable a space circular economy including the reuse of spacecraft solar arrays [49]. Solar cells degrade rapidly in space due to radiation and temperature changes and might not be directly reusable [49]. Thus, processes to reuse their materials must be investigated such as the use of plasma generators [49].

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6. Discussion

Technologies transfers between industries have the potential to assess the challenges of sustainability and circularity and should be encouraged. Nonetheless, technology transfers are not innate to industries since they depend on different factors such as their network, their direction, and their opportunities [50]. Technology transfers remain rare because they are often the result of an encounter [50]. Financing organizations are existing at different levels such as at the European level, national or regional level, and from private actors [50]. Clusters are also important to enhance technology transfers as they permit industries to build a network within their domain [50]. Moreover, the technical characteristics of the technology itself increase the chance of success of the technology transfers as the versability, integrability, flexibility, and reliability of the technology to be transferred [52]. Other features favor the success of the technology transfer such as a collaborative system that promotes the participation of private actors., the provision of a prototype, the technical reports, and the communication between the project members to facilitate the transfer [52]. ESA studies on technology transfers and demonstrate that factors are important for the characterization of the transfer: the degree of maturity of the technology to be transferred, if the technology is mission-orientated or diffusion oriented, and the anticipation of common technology needs between the space industry and other industries [53]. The nature of the network of the participant in the technology transfer and the internal structure of their organization are also important in the success of the transfers [53]. Thus, to enhance technology transfers between space and aviation the creation of a bridge between the two industries and communities is crucial. It should be expanded to other industry sectors such as the energy sector.

7. Conclusion

The technology transfer methods have been defined with past examples of technology transfer between the aviation and the space industry. The news challenges: sustainability and circularity have been described for each industry. Potential spin-offs and spin-ins to assess those challenges have been proposed.

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References

[1] European Commission. 2022. *Reducing emissions from aviation*. [Online]. [Accessed 19 June 2023]. Available from: https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-aviation_en
[2] Pierotti. M. 2022. *Sustainability and the Aviation Industry*. Buckinghamshire New University
[3] Geleynse. S., Brandt. K., Garcia-Perez. M., Wolcott. M., Zhang. X. 2018. The Alcohol-to-Jet Conversion Pathway for Drop-In Biofuels: Techno-Economic Evaluation. *ChemSusChem Chemistry-Sustainability-Energy-Materials*, **11**(21), pp.3728-3741.
[4] McKinsey & Company. 2020. *Sustainable aviation today for clean skies tomorrow*. [Online]. [Accessed 19 June 2023]. Available from: https://www.youtube.com/watch?v=4Ln3YK0MNXo
[5] Ydersbond. I. M., Kristensen. N. B., Thune-Larsen. H. 2020. *Nordic Sustainable Aviation*. Nordic Energy Research.
[6] Yusaf. T., Fernandes. L., Talib. A. R. A., Altarazi. Y. S. M., Alrefae. W., Kadirgama. K., Ramasamy. D., Jayasuriya. A., Brown. G., Mamat. R., Al Dhahad. H., Benedict. F., Laimon. M. 2022. Sustainable Aviation—Hydrogen Is the Future. *Sustainability*. **14**(548).
[7] Air bp. 2022. *What is sustainable aviation fuel (SAF)?*. [Online]. [Accessed 19 June 2019]. Available from: https://www.bp.com/en/global/air-bp/news-and-views/views/what-is-sustainable-aviation-fuel-saf-and-why-is-it-important.html
[8] *OECD. 2014.* The spin-offs from space investments. *The Space Economy at a Glance*. OECD Publishing. Paris. https://doi.org/10.1787/9789264217294-26-en
[9] Arte Family FR. 2023. Gutenberg, l'inventeur visionnaire | Points de repères | ARTE. [Online]. [Accessed 19 June 2023]. Available from: https://www.youtube.com/watch?v=MWs-aSpgzNg
[10] Rohrbeck. R., Döhler. M., Heinrich. A. M. 2007. Combining spin-out and spin-in activities – the spin-along approach. *ISPIM 2007 conference, 17th - 20th June 2007, Warsaw*. pp.12

DOI: 10.13009/EUCASS2023-556

[11] Jagersma. P. K., Van Gorp D. M. 2003. Spin-out management: theory and practice. *Business Horizons*. **46**(2). pp. 15-24

[12] Terem. 2021. *What is a Tech Spinout?*. [Online]. [Accessed 19 June 2023]. Available from: https://terem.tech/what-is-a-tech-spinout/#:~:text=A%20tech%20spinout%20is%20where,revenue%20source%20or%20competitive%20advantage

[13] Michl. T., Gold. B., Picot. A. 2012. The spin-along approach: ambidextrous corporate venturing management. *International Journal Entrepreneurship and Small Business*. **15**(1). pp.39-56

[14] IAF. 2011. *History of the GPS Program*. [Online]. [Accessed 19 June 2023]. Available from: https://www.aiaa.org/docs/default-source/uploadedfiles/about-aiaa/press-room/videos/iaf-60th-anniv-gps-nomination.pdf?sfvrsn=9bc64bfa_0

[15] Pace. S., Frost. G., Lachow. I., Frelinger. D., Fossum. D., Wassem. D. K., Pinto. M. 1995. *The Global Positioning System Assessing National Policies*. Santa Monica: RAND

[16] Sturza. M. A. 1983. A GPS navigation set for commercial aviation applications. *Aerospace Congress and Exposition*. *03 October 1983. United States*

[17] Ochieng. W. Y., Sauer. K., Walsh. D., Brodin. G., Griffin. S., Denney. M. 2003. GPS Integrity and Potential Impact on Aviation Safety. *The Journal of navigation*. **56**(1). pp.51-63.

[18] Skybrary. *Required Navigation Performance (RNP)*. [Online]. [Accessed 19 June 2023]. Available from: https://skybrary.aero/articles/required-navigation-performance-rnp

[19] Skybrary. *Performance Based Navigation (PBN)*. [Online]. [Accessed 19 June 2023]. Available from: https://skybrary.aero/articles/performance-based-navigation-pbn

[20] ICAO. *Performance-Based Navigation (PBN) Frequently Asked Questions (FAQ)*. [Online]. [Accessed 19 June 2023]. Available from: https://www.icao.int/safety/pbn/miscellaneous%20items/pbn%20faqs.pdf

[21] Griffin. M. D. 2007. *Spinoff 2007*. [Online]. [Accessed 19 June 2023]. Available from: https://spinoff.nasa.gov/Spinoff2007/PDF/basic_version_07.pdf

[22] Kelly Aerospace. 2009. Break the Ice ThermaWing is the most advanced de-icing system on the market [Advert]. [Online]. [Assessed 19 June 2023]. Available from: http://www.kellyaerospace.com/articles/Kelly%20Aerosource%20Dec.%202009%20Cessna%20Story.pdf

[23] García Márquez F.P., Pinar-Pérez J.M. 2020. Chapter 4 - Non-destructive testing for the evaluation of icing blades in wind turbines. *Introduction to non-destructive testing and condition monitoring techniques for renewable energy industrial assets*. [Online]. Oxford: Butterworth-Heinemann. [Accessed 19 June 2023]. Available from: https://www.sciencedirect.com/science/article/pii/B9780081010945000046

[24] O'Keefe S. 2002. *Spinoff National Aeronautics and Space Administration*. [Online]. [Accessed 19 June 2023] Available from: https://spinoff.nasa.gov/spinoff2002/spin02.pdf

[25] Cox & Company. 2023. *Low Power Ice Protection Systems*. [Online]. [Accessed 19 June 2023]. Available from: https://www.coxandco.com/low_power_ips.html

[26] Cardoso da Silva. C. D. 2012. *Integrated Modular Avionics for Space Applications: Input/Output Module*. Dissertation, Instituto Superior Técnico.

[27] Fleming. C. H., Leveson. N. G. 2014. Improving Hazard Analysis and Certification of Integrated Modular Avionics. *Journal of aerospace information systems*. **11**(6).

[28] ESA. 2021. *Can Integrated Avionics from Aviation Industry be Applied to Space?*. [Online]. [Assessed 19 June 2023]. Available from: https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/Can_Integrated_Avionics_from_Aviation_Industry_be_Applied_to_Space

[29] Deredempt. M., Rossignol. A., Hyounet. P. 2013. Integrated modular avionics for spacecraft: Earth Observation use case demonstrator. *DASIA, 14-16 May 2013, Porto, Portugal* ESA SP-720

[30] ESA. 2021. General Support Technology Programme Annual Report 2021. [Online]. [Accessed 19 June 2023]. Available from: https://esamultimedia.esa.int/docs/technology/GSTP_Annual_Report_2021_Final.pdf

[31] Clauss, M., Weiss, B., Laufer, R., Öhrwall Rönnbäck, A., and Losch, A. 2022. Creaternity Space: In search of circularity for reuse of spacecraft materials, 73rd International Astronautical Congress, Paris, France, IAC-22-E6,3,2, x69410

[32] Spacewatch. global - News Room. 2022. Space Café WebTalk - Kai Uwe Schrogl - 16. August 2022. [Online]. [Accessed 19 June 2023]. Available from: https://www.youtube.com/watch?v=QFuYjRQjGis

[33] FutureSky. 2019. Circular aviation a research programme of the future sky joint research initiative

[34] Thomson. R., Weichenhain. U., Sachdeva. N., Kaufmann. M., Gupta. A., Stern. C., Trueman. N. 2020. *Hydrogen | A future fuel for aviation?*. Munich: Roland Berger GMBH

[35] Llewellyn. G. 2021. *Hydrogen An energy carrier to fuel the climate-neutral aviation of tomorrow*. Toulouse: AIRBUS

DOI: 10.13009/EUCASS2023-556

[36] NASA. 2021. *Space Applications of Hydrogen and Fuel Cells*. [Online] [Accessed 20 June 2023] Available from: https://www.nasa.gov/content/space-applications-of-hydrogen-and-fuel-cells
[37] Yazigi. P. 2019. Combustion Instabilities and Oscillations in Solid Propellant Rockets. PSIEL 41. Modules Electifs. 2019. Institut Polytechnique des Sciences Avancées IPSA
[38] Perez Ramos. R. 2019. Nuclear Rocket Propulsion. PSIEL 41. Modules Electifs. 2019. Institut Polytechnique des Sciences Avancées IPSA
[39] NASA. 2010. *Liquid Hydrogen--the Fuel of Choice for Space Exploration*. [Online]. [Accessed 20 June 2023]. Accessed from: https://www.nasa.gov/topics/technology/hydrogen/hydrogen_fuel_of_choice.html
[40] Johnson R.G. 2021. History and Use of LH2 Cryogenic Storage and Transfer Systems at KSC. DOE/NASA Advances in Liquid Hydrogen Storage Workshop. 2021. NASA
[41] Fesmire J.E., Swanger. A. 2021. Overview of the New LH2 Sphere at NASA Kennedy Space Center. DOE/NASA Advances in Liquid Hydrogen Storage Workshop. 2021.NASA
[42] Colozza. J.A. 2002. Hydrogen Storage for Aircraft Applications Overview. NASAl CR-2002-211867
[43] Bushliner Aircraft. 2023. *Our Process*. [Online] [Accessed 20 June 2023]. Available from: https://bushliner.com/about-2/about/
[44] AELS. 2023. *AELS's website*. [Online]. [Accessed 20 June 2023]. Available from: https://aels.nl/
[45] Sundin. E. 2021. Remanufacturing, P10: Sustainable Development #3, 2021-11-16, Linköping University
[46] Rossetti. D., Keer. B., Panek. J., Reed. B., Cepollina. F., Ritter. R. 2015. Spacecraft Modularity for Serviceable Satellites. *AIAA SPACE 2015 Conference and Exposition. 31 Aug-2 Sep 2015. Pasadena, California*
[47] Moraguez. M. T. 2018. *Technology Development Targets for Commercial In-Space Manufacturing.* PhD thesis. Massachusetts Institute of Technology
[48] Kulu. E. 2022. In-Space Manufacturing - 2022 Industry Survey and Commercial Landscape. *73rd International Astronautical Congress (IAC 2022). September 2022. Paris, France*
[49] Clauss. M., Cho.M., Herdrich. G., Laufer. R. 2023. Recycling & Reusing spacecraft solar panels: A planned experimental research approach. *34th International Symposium on Space Technology and Science. June 3-9, 2023. Kurume, Japan*
[50] Institut de Relations Internationals et Stratégiques. 2015. *Origines des technologies critiques dans l'industrie de défense en France : spin-ins ou spin-offs entre la défense et le civil ? traitement qualitatif et quantitatif synthèse de l'étude*. Paris : Institut de Relations Internationales et Stratégiques. [Online]. [Accessed 20 June 2023]. Available from: https://www.iris-france.org/wp-content/uploads/2016/03/EPS2014-Spin-In-Spin-Off-synthèse.pdf
[51] Goraj. Z. 2004. An overview of the deicing and anti-icing technologies with prospects for the future. *24TH International Congress of the Aeronautical Sciences. 29 August 3 September 2004. Yokohama. Japan*
[52] Venturini. K., Verbano. C., Matsumoto. M. 2013. Space technology transfer: Spin-off cases from Japan. *Space Policy*. **29**(1), pp 49-57
[53] Bach L, Cohendet P, Schenk E. 2002. Technological transfers from the European space programs: a dynamic view and comparison with other R&D projects. *The Journal of Technology Transfer*. **27**, pp 321-38. Doi: 10.1023/a:1020259522902. PMID: 14983843
[54] Carayannis. E. G., Rogers. E. M., Kurihara. K., Allbritton. M. M. 1998. High-Technology spin-offs from government R&D laboratories and research universities. *Technovation*. **18**(1), pp 1-11. Doi: https://doi.org/10.1016/S0166-4972(97)00101-6
[55] Tidd. J., Barnes. S. 2000. Spin-in or spin-out? Corporate venturing in life sciences. *International Journal of Entrepreneurship and Innovation*. **1**(2), pp 109-116. Doi: https://doi.org/10.5367/000000000101298603