8 (1): 7-14 (2024)

Journal of Aviation

https://dergipark.org.tr/en/pub/jav

e-ISSN 2587-1676

Assessing the Environmental Impact of Aircraft Maintenance

Haşim Kafalı

Muğla Sıtkı Koçman University, Aviation Management Department, 48770, Dalaman, Muğla, Türkiye. (hasimkafali@mu.edu.tr).

Article Info

Received: 11 December 2023
Revised: 23 January 2024
Accepted: 08 February 2024
Published Online: 22 February 2024

Keywords:
Aircraft maintenance
Environmental effects
Maintenance planning
Aeronautics

Corresponding Author: *Haşim Kafalı*

RESEARCH ARTICLE

https://doi.org/10.30518/jav.1403284

Abstract

This study intends to investigate the maintenance of the sample aircraft under C-check with the environmental impact approach. With this research, maintenance of both aircraft types is divided into related subsystems and total process hours are determined in man-hours. Thus, it is aimed to show that environmental impacts should be taken into consideration in maintenance planning. The environmental effects that occur during aircraft maintenance operations are analysed. Environmental impact analysis, a basic life cycle analysis, is conducted under ISO 14044. Impacts (Impact on Human Health, Impact on Ecosystem Quality Impact and Resources Impact) have been calculated according to the Eco-Indicator99 database using SimaPro, which is the Life Cycle Analysis program. In the light of all results, it is seen that the C-check for Boeing 737 has a significant negative impact on the resources, ecosystem quality, and human health especially in all ATA100 categories.

1. Introduction

It has been mentioned that an aircraft carries passengers or cargo from one place to another for a while, effectively, efficiently, and safely, at any time in its service life. To perform this operation, it is necessary to perform repair and renewal work. These processes are called maintenance. And also, modern aircraft have thousands of parts, systems, subsystems and components that need to be maintained after certain flight hours, flight cycles, calendar days or months (as these are known as usage parameters) (Witteman et al., 2021).

According to the Directive on Continuous Airworthiness and Maintenance Responsibility (SHT-M) issued by the Directorate General of Civil Aviation (DGCA), maintenance is subject to repair, revision, replacement, inspection, modification or troubleshooting of an aircraft or component, except pre-flight control or any combination of these (DGCA, 2018). In Crocker's Dictionary of Aviation maintenance is described as service, repair, modification, inspection, and due diligence activities to restore a system or keep it operational (Crocker, 2007). While there are many studies defining maintenance (Kinnison et al., 2013; Shanmugam et al., 2015; Lin et al., 2017; Kafalı et al., 2019), maintenance is defined as the process by which it is ensured that a system is continuously performing its intended function at the level of reliability and safety in this study.

The main purpose of maintenance is to keep the aircraft at design limits in terms of performance and reliability even after manufacture (Friend, 1992; Papakostas et al., 2010). The classification and content of aircraft maintenance activities are determined by the aircraft manufacturer. Producers present all maintenance activities and directives to the users in a detailed document called MRB (Maintenance Review Board). Besides, considering the long service life of aircraft, manufacturers publish various documents under the name Service Bulletins to inform aircraft operators and owners of unsafe conditions that need special inspections, modifications or repairs, and also to notify users of technological innovations and changes during this period (Wang et al., 2017; Kala et al. 2022).

Aircraft maintenance planning is the process by which planners or engineers in the maintenance company organize the maintenance process for later periods. For the efficient implementation of the aircraft maintenance planning process, the maintenance company must either create its own maintenance management program or use one of the available programs. Otherwise, the maintenance planning process cannot go beyond repeating existing operations (Pintelon et al., 2009; Gopalan, 2014; Wen et al., 2022). This maintenance management program may include a number of maintenance-related topics, such as the time period by which technicians will be performed, the cost, the equipment or equipment to be used. The main objective of maintenance is to maintain the performance and reliability of the aircraft within the specified design limits after the delivery to the operator. For this purpose, it is mandatory to establish and implement an appropriate maintenance program also for safety and for reducing costs (Pintelon et al., 2009; Gopalan, 2014; Yadav, 2010; Yu et al., 2011; Lestiani et al, 2017).

Studies have shown that aviation accidents have decreased with better planning and regulation of maintenance activities. For example, while the annual accident rate per million flights was 10 on average in the 1960s, this rate has decreased to 0.05 today. This success has been achieved thanks to the meticulous and regular maintenance activities applied in aircraft maintenance (Shaukat et al., 2020). Aircraft maintenance must be well planned and managed in terms of both ensuring flight safety and reducing maintenance costs and environmental impacts. Especially in the field of aviation, it is important to reduce maintenance costs due to the very expensiveness of aircraft parts and components. This high value products and components are technology intensive, high priced and reliability required services (Fedotova et al., 2013; Ezhilarasu et al., 2019).

According to IATA's 2017 data, the aviation industry spent 76 billion dollars annually for commercial aviation maintenance and this value is estimated to be 118 billion dollars for 2027. Based on these data, the increase in maintenance costs and therefore environmental wastes arising from maintenance will increase day by day. In order to reduce maintenance costs and environmental impacts of maintenance, the importance of maintenance planning is increasing (Ezhilarasu et al., 2019). Therefore, maintenance organizations develop and implement new and valid maintenance programs (Iwata et al., 2013; Verhoeff et al., 2015; Ceruti et al., 2019; Yu et al., 2019; Sanderson et al., 2020). These prepared maintenance programs will increase the usability and reliability of the aircraft, reduce the undesired ground time of the aircraft and accidents, and decrease the aircraft maintenance costs and environmental impacts of the maintenance (Ezhilarasu et al., 2019; Iwata et al., 2013; Saltzman et al. 2022; Ma et al., 2022).

Some papers have handled the optimization of maintenance. These can be classified into two groups. The first group of studies is concerned with optimizing the overhaul and man-hour-work planning, using methods of job scheduling and planning (Gray, 1992; van Rijn et al., 1992; Dijkstra et al., 1994; Dekker et al., 1998; Keivanpour et al., 2015). The second group considers maintenance optimization which focuses on engine, aircraft, and aerospace maintenance technology and deals with some solutions to reduce the maintenance costs (Keivanpour et al., 2015; Tanaka et al., 2003; Fang et al., 2015). Further studies focused on optimization models, using the genetic algorithm developed to support maintenance substructure. The purpose of these models is to optimize the aircraft maintenance and maintainability during the design phase for minimum life cycle cost (LCC) or according to the objective function of cost minimization (Saranga et al., 2006; Yang et al., 2012).

It is seen that managing the maintenance carried out in airline companies involve only economic parameters. Furthermore, it is seen that environmental impacts and environmental parameters are not on the agenda of most airlines. It is important to consider environmental factors, which is one of the important pillars of sustainability (Altuntas et al., 2019). Wastes from aircraft, because of the end of life parts, cause the environmental impacts, which are significant and unneglectable in the life cycle assessment (LCA) (Keivanpour et al., 2015; Tanaka et al., 2003; Fang et al., 2015; Saranga et al., 2006; Yang et al., 2012; Altuntas et al., 2019; Mascle et al., 2015).

The growing of the number of aircraft is expected to continue. It is estimated around 47,600 in 2038 (Airbus, 2019; Boeing, 2019). It is important that the environmental aspects of aircraft are considered, and that additional studies are carried out to successfully deal with the maintenance impact of aircraft maintenance. Understanding and learning aircraft maintenance impacts on the environment naturally emerge as a very important aviation field. Therefore, the aeronautical industry is facing increasing pressure to develop more efficient and sustainable aircraft maintenance programs to mitigate their impact on the environment. This social responsibility obliges aircraft manufacturers and owners to take this impact into account and propose solutions to reduce the environmental impacts of the maintenance operations.

In this study, the environmental impacts of two different aircraft types Being 737 and Airbus 320, in terms of maintenance timing were investigated.

1.1. System Description

After the production of a new type of aircraft, the manufacturer has to prepare the initial maintenance program and give it to the operators. Maintenance programs are being developed from the design stage of the aircraft, and issues that are not approved are corrected at these stages. The initial maintenance program (MRB) includes minimum maintenance requirements for maintenance and is approved by the aviation authority of the manufacturer country. The manufacturer publishes the Maintenance Planning Documents (MPD), which contain maintenance recommendations, which include the entire maintenance initial report (Knotts, 1999; Muchiri, 2002). Operators begin to use the Airline Maintenance Program by using all documents and have them approved by local authorities. Operators can update the maintenance program implemented over time (Muchiri, 2002). The operator who creates the maintenance program then performs the maintenance in accordance with the planned maintenance types defined in the maintenance program. Maintenance Check Types and Intervals for each type of aircraft in each operator's fleet are specified (Friend, 1992; Atak et al., 2011). Prior studies, according to the available literature, are limited by the function of hours of flight time, a number of landing – take-off, and calendar length of time from prior maintenance (Keivanpour et al., 2015; Yang et al., 2012). And previous studies also suggest that the replacement of parts and components, repairs, and waste during maintenance operations are the most important categories of maintenance and repairing activities that can be considered in terms of environmental impacts (Yadav, 2010; Dekker et al., 1998; Airbus, 2019; Boeing, 2019).

The classification is shown as ATA systems. ATA chapters also help all airline workers. To find the exact point of parts and more, they search on its ATA scale. Classification of the maintenance can be changed for all aircraft manufacturers. But the main body of ATA chapters is the same. ATA Chapters of Airbus and Boeing aircraft are shown in Figure 1 (Airbus AMM, 2004; Boeing AMM, 1999).

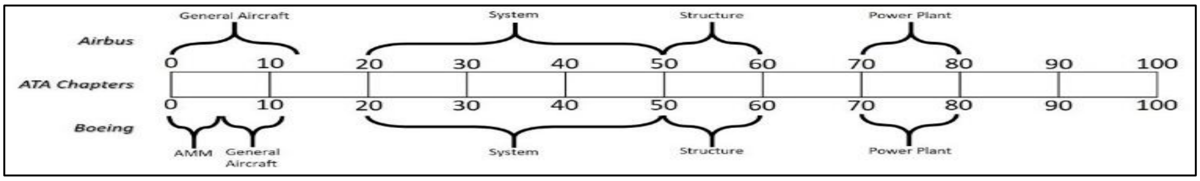

Figure 1. Maintenance classification for Airbus and Boeing (Airbus AMM, 2004; Boeing AMM, 1999)

1.2. Environmental Impact Assessment

The majority of the activities at airports cause various environmental impacts. When the literature is examined, it is seen that there is much software that determines these effects and there are many data banks that use these data (Goedkoop et al., 2000; Altuntas et al., 2013). In this study, all other processes of both aircraft types were excluded from the scope of the environmental evaluation, and only the works performed during maintenance, and the parameters spent were taken into consideration.

Due to urban development and change, airport zones remain in the city over time, causing noise, water pollution, and air pollution. The resulting noise can affect the quality of life of the people living in the region in terms of physical, physiological, psychological, and performance and may cause health problems. In aircraft, auxiliary power sources produce a large number of toxic emissions that negatively affect air quality when operating during maintenance. These toxic substances can cause serious diseases in human health (Altuntas et al., 2013; Cleveland, 2004; Altuntas et al., 2011). At the same time, during the maintenance, while changing oil, fuel, and various chemicals, there are some leaks, spills, splashes that occur. Over time, these substances are transported by underground water and sewerage systems and cause problems in the lives of the people in the region.

Environmental aspects of aircraft maintenance include the use and disposal of aircraft and vehicle fluids such as (US Environmental Protection Agency, 1998):

- Wastewater from parts cleaning, metal finishing, or coating applications.

- Generation of hazardous wastes consisting of flammable and metals-contaminated solvents, used hand-wipes, and sludges collected during all maintenance operations.

- Hazardous air pollutant (HAP) emissions from solvent-based cleaners and coatings used in all activities.

The wastes arising from the maintenance and repair operations of aircraft and aviation-support vehicles encompass a range of materials, including used oil, spent fluids, batteries, metal machining wastes, organic solvents, and tires. Some of these waste materials possess toxicity or other hazardous characteristics, and if not properly managed, uncontrolled releases have the potential to contaminate surface water, groundwater, and soils. Table 1 identifies the typical materials employed in each operation and outlines the potential impacts associated with the use and disposal of these materials (US Environmental Protection Agency,1998).

Table 1. Operations performed in aircraft maintenance practices and their environmental aspects and potential impacts (US Environmental Protection Agency,1998)

Operation	Environmental Aspects and Potential Impacts
Lubrication and Fluid Changes	It has the potential to pollute soil, groundwater, and surface waters in case of a spill or if it is allowed to enter storm drains.
Battery repair and replacement	The ability to pollute soil, groundwater, and surface waters with hazardous materials exists unless properly contained and shielded from adverse weather conditions.
Chemical Milling Maskant Application and Chemical Milling	Airborne pollution resulting from the release of organic HAPs (hazardous air pollutants) originating from waste maskant.
Parts Cleaning	Water contamination arising from wastewater containing cleaning agents, discarded solvents, metals, oil, and grease. Additionally, there is air pollution due to the emission of organic hazardous air pollutants (HAPs).
Metal Finishing	Air pollution resulting from hazardous air pollutant (HAP) emissions; polluted wastewater containing cyanide solutions, corrosive acids and alkalis; and sludges containing heavy metals.
Coating Application	Airborne pollution originating from emissions of organic hazardous air pollutants (HAPs), as well as waste paint and discarded solvent thinners.
Depainting	Contaminated sludge (resulting from stripper solution and paint residue); air pollution caused by volatile organic compound (VOC) emissions from paints; solid waste comprising paint chips and used blasting media.
Painting	Contamination of soil or water due to the disposal of waste paint, thinners, solvents, and resins; air pollution resulting from volatile organic compound (VOC) emissions.

2. Materials and Methods

The two major aircraft manufacturers (Airbus and Boeing) have different maintenance schedule from each other. The boundary between A-Check and C-Check is very complex for both the aircraft manufacturers and their customers. Therefore, in so many airlines, maintenance intervals are created according to flight hours, the number of flights, or monthly (calendar month). C-Check maintenance for Boeing 737 and Airbus A320 are investigated with this study. According to refs. (Airbus AMM, 2004; Boeing AMM, 1999) and as a result of bilateral negotiations with Turkish Airlines, Anadolu Jet, Sun Express, Onur Air, Corendon and Pegasus, which are airlines operating in Turkey, maintenance processes and man-hours were determined.

While the C-check maintenance of the Airbus 320 takes 94.5 man-hours, this value was calculated as 44.29 man-hours in Boeing 737. These values are mean-values and were calculated according to expert review. However, aircraft operators include a certain number of personnel in the maintenance to be applied to save time and this period varies from company to company.

With the classification method of Airbus and Boeing companies, C-check of Airbus A320 and Boeing 737 aircraft are categorized. After the assessment for Airbus A320, it was seen that the maintenance package included 66.58 man-hours of work under the ATA100-System categories, 0.33 man-hours of ATA100-Structure categories, and 27.59 man-hours of ATA-100-Powerplant categories. In the maintenance of Boeing, man-hours are calculated as 32.33, 2.15, and 9.92 in ATA100-System, ATA100-Structure, and ATA100-Powerplant categories, respectively. In addition to the man-hours, some spare parts changing and using the lubricants were determined and added to the environmental calculations.

Ground operations are carried out in the city centre, the emission of all vehicles on living spaces has a direct impact on human health, ecosystem quality, and natural resources. Considering all this, environmental analysis should be carried out to determine the environmental impacts of air pollution. Environmental impact analysis, a basic life cycle analysis, is conducted under ISO 14044. Impacts (Impact on Human Health, Impact on Ecosystem Quality Impact and Resources Impact) can be calculated according to the Eco-Indicator99 database using SimaPro, which is the Life Cycle Analysis program (Goedkoop et al., 2000; Altuntas et al., 2013).

All impact categories and their measurement units are demonstrated in Table 2. The table shows the aircraft maintenance characterization under the Eco-indicator99 baseline. There are three endpoints (Human health, Resources and Ecosystem quality) in this method. Human Health impact is measured as DALY (disability-adjusted life years). One DALY can be considered a lost year of a healthy life. Human health impact includes respiratory and carcinogenic damage, global trade, and increased precipitation, all causes of ozone depletion. Ecosystem quality impact is measured as PDF*m^2*yr (all species' disappearing from one m^2 area for one year). Also, in here PDF is potentially disappeared fraction. Ecosystem quality damages are the result of the combined effect of acidification and eutrophication, ecotoxic emissions, and land occupation and conversion. Resources impact indicates the extinction of unused natural energy sources and is measured as MJ surplus. The results of these impacts indicate the future generational effects of today's overused energy sources (Goedkoop et al., 2000; Altuntas et al., 2013; Cleveland, 2004; Altuntas et al., 2011, Altuntas, 2014; Altuntas, 2021; Kafalı et al., 2020).

Table 2. Impact categories

Endpoints	Midpoints	Impact units	Weighted units
Human Health	Carcinogens	DALY	Pt
	Resp. organics	DALY	Pt
	Resp. inorganics	DALY	Pt
	Climate change	DALY	Pt
	Ozone layer	DALY	Pt
Ecosystem quality	Ecotoxicity	PAF*m^2yr	Pt
	Acidification/ Eutrophication	PDF*m^2yr	Pt
	Land use	PDF*m^2yr	Pt
Resources	Minerals	MJ surplus	Pt
	Fossil fuels	MJ surplus	Pt

3. Result and Discussion

Aircraft maintenance requires a large amount of energy. For this purpose, manufacturers and companies use many natural energy sources such as fossil fuels. When the developing and increasing aircraft industry is considered, it is certain that the amount of impact will increase. Human health impact, ecosystem quality impact, and resource impact of maintenance procedure for man-hours were calculated using the SimaPro-7.3 software (PRéConsultant, 2019).

There are ten sub-categories, under the three-main categories, for our results. Carcinogens, resp. organics, resp. inorganics, climate change is the ozone layer are calculated under the human health impact. While ecotoxicity, acidification/eutrophication, and land use are involved in ecosystem quality impact, minerals and fossil fuels are listed under the resource impact. Weighted value is a tool that can help to compare different impact categories under the same unit. Weighted values of C-check for Airbus A320 and Boeing 737 were drawn in Figure 2.

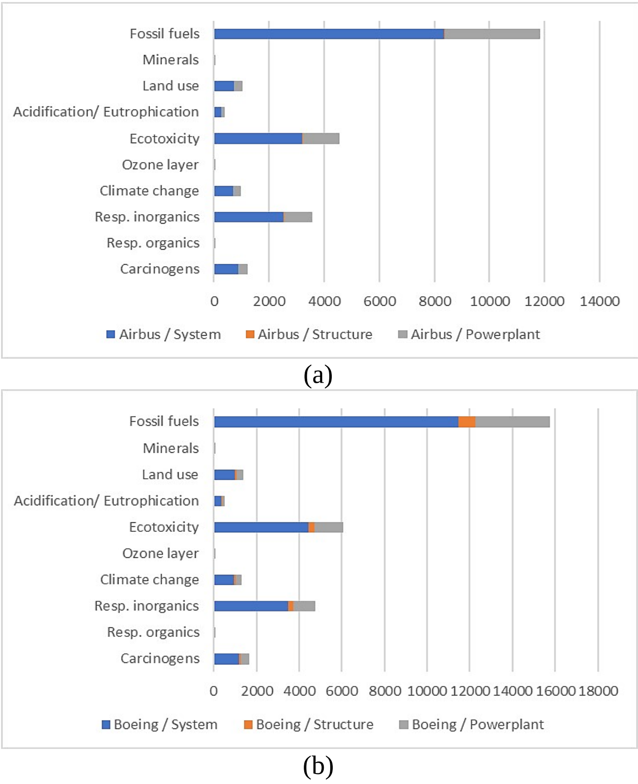

Figure 2. Weighted values of C-check for (a) Airbus and (b) Boeing (in Pts)

As shown in Figure 2, "a" presents Weighted values of C-check for Airbus A320, and "b" presents weighted values of C-check for Boeing 737. Total weighted values were calculated as 23.66 and 31.55 kPts for Airbus A320 and Boeing 737, respectively. In the results of Airbus A320, while the maximum weighted value was found as 16.68 kPts in the ATA100-System category, the minimum weighted value was calculated as 82.05 Pts in ATA100-Structure categories. In the results of Boeing 737, while the maximum weighted value was found as 22.96 kPts in the ATA100-System category, the minimum weighted value was calculated as 1528.24 Pts in ATA100-Structure categories. The average weighted values for each ATA100 category are 7.88 and 10.52 kPts for Airbus A320 and Boeing 737, respectively. It seems that the C-check of Boeing 737 has an average of 33% higher environmental impact than the C-check of Airbus A320.

The increasing number of aircraft and the consequent increase in maintenance activities bring greater environmental problems. External ground sources, which are operated during maintenance, create serious problems for living organisms and the ozone layer. However, solid, liquid, and gas wastes that occur during maintenance affect the green areas such as trees and grass negatively. Disposal of liquid wastes used in maintenance by sea, lake, and riverbeds in various ways has negative consequences on the ecosystem. The ecosystem quality impact of C-checks is shown in Figure 3.

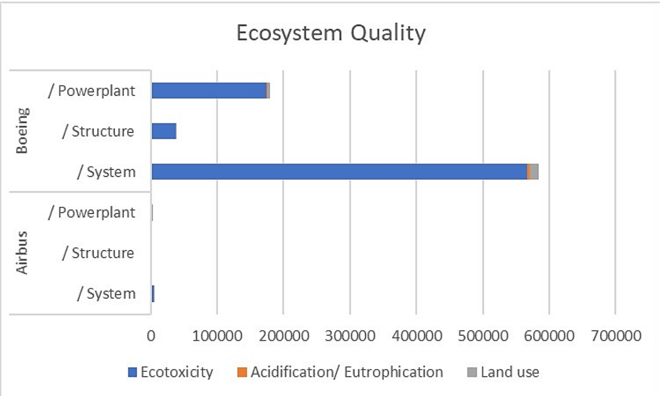

Figure 3. Ecosystem Quality Impact values of C-check (in PDF*m^2*yr)

The ecosystem quality impact was investigated under the three midpoints. According to results, ecotoxicity has the most impacts on all ATA100 categories. The results of the ecosystem quality impact indicate the Boeing 737 (with the total value of 802628 PDF*m^2*yr), and especially ATA100-system categories (72.77% of the total value). In Airbus A320, While the ecotoxicity impact was calculated as 6072.43 PDF*m^2*yr, the impact values of Acidification/Eutrophication and Land use were found as 500,53 and 1380,21 PDF*m^2*yr, separately. The total ecosystem quality impact value of C-check for the Boeing 737 was found to be a-hundred-times higher than the Airbus A320. Another impact category, Human Health Impact, was represented in Figure 4.

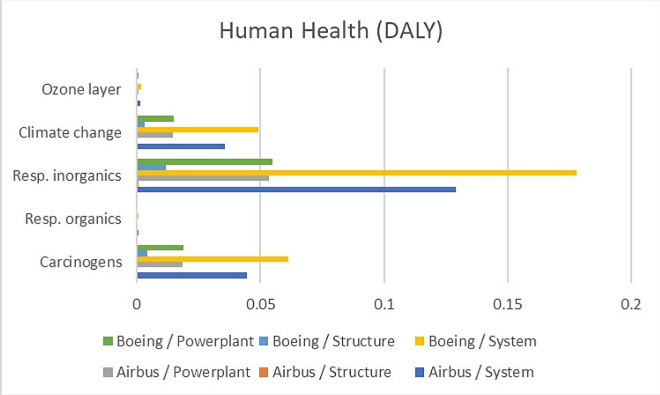

Figure 4. Human Health Impact values of C-check (in DALY)

Considering the C-check maintenance activities, calculated as 94.50 man-hours for Airbus A320 and 44.29 man-hours for Boeing 737, it is seen that the environmental problems created can have serious negative effects on human health. Comprehensive maintenance activities on Airbus aircraft make it time-consuming and can cause serious environmental damage to human health. As pointed out in Figure 4, while the maximum human health impact was calculated to be 0.29 DALY at the ATA100-system categories for Boeing 737, the minimum human health impact was calculated to be 0.001 DALY at the ATA100-structure categories for Airbus A320. The total human health impacts for Boeing 737 and Airbus A320 are 0.4 and 0.3 DALY, separately.

Resources impacts are pointed out in Figure 5. While the impact of the maximum resource was calculated to be 322.06 GJ at the ATA100-system categories for Boeing 737, the impact of the minimum resources was calculated to be 1150.81 MJ at the ATA100-structure categories for Airbus A320. The total resource impact for Boeing 737 and Airbus A320 are 442.54 and 331.91 GJ, separately.

In addition to the results obtained, carrying out aircraft maintenance practices in a sustainable and more environmentally friendly manner without compromising safety requires a comprehensive examination of the stakeholders and the identification of their relevant needs, expectations and mutual relationships (Keivanpour et al., 2015).

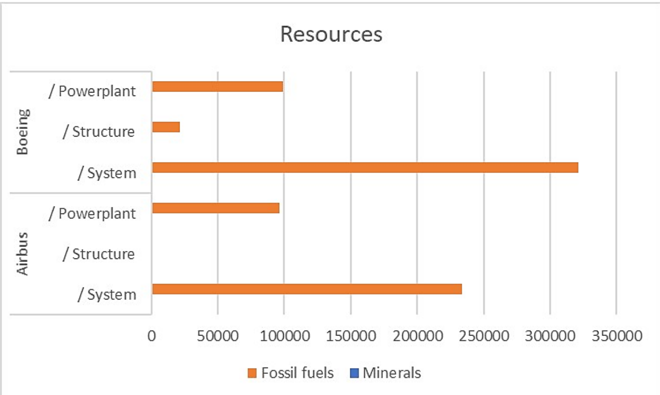

Figure 5. Resources Impact values of C-check (in MJ Surplus)

Manufacturers should furnish a suitable maintenance manual incorporating objectives that systematically consider environmental concerns, evaluate the environmental impact associated with maintenance activities, and comply with pertinent policy, regulatory requirements, and applicable

standards. Moreover, the manual should diligently address relevant best practices, with the overarching goal of preventing or mitigating adverse environmental impacts throughout the course of maintenance activities (Keivanpour et al., 2015).
Various methodologies and approaches are available to manufacturers for implementing Design for Environment in their design processes. Material substitution, design for disassembly, design for recyclability, and design for reusability represent a subset of methodologies employed by manufacturers. Moreover, an integrated eco-design approach mandates the inclusion of stakeholders, a life cycle perspective, and multi-criteria decision analysis (Keivanpour et al., 2015).

4. Conclusion

The increasing demand and interest in assessing the social and environmental impacts of a product throughout its life cycle highlight the necessity for manufacturers to adopt a sustainable approach when optimizing product characteristics during the design phase. Aircraft represent one of the costliest industrial systems, simultaneously imposing the highest standards for reliability and safety. The aerospace industry, dealing with intricate and expensive products and demanding elevated levels of safety and reliability, encounters additional challenges in integrating a sustainable approach during the design phase. The maintenance process plays a crucial role in the aircraft's life cycle, taking into account both the environmental consequences and operational costs.

According to experts (especially Turkish technicians and engineers) on maintenance and reference books, published by the manufacturer, some results were found under exact conditions for Turkey. All these results and implements were created from the airline operators in Turkey. In the light of all results, it is seen that the C-check for Boeing 737 has a significant negative impact on the resources, ecosystem quality, and human health especially in all ATA100 categories. Some conclusions of this study are highlighted below.

- While the total weighted value for each ATA100 category is 23.66 kPts and 20.07 kPts for Airbus A320 and Boeing 737, respectively, the average weighted values for each ATA100 category are 7.88 and 10.52 kPts for Airbus A320 and Boeing 737, respectively. According to average values, the C-check of Boeing 737 has a 33% higher environmental impact than the C-check of Airbus A320.

- The highest weighted value was calculated as 15.77 MPts in fossil fuels impact for Airbus. The minimum weighted value was found as 13.73 pts in respiration organics impact for Airbus.

- The maximum impact values (ecosystem quality, human health and resources) were found as 0.29 DALY, 584104.5 PDF*m^2*yr, and 322.06 GJ for the ATA100-system category of C-check for Boeing 737. The minimum impact values (human health, ecosystem quality, and resources) were calculated as 0.001 DALY, 385.23 PDF*m^2*yr, and 1150.81 MJ for the ATA100-structure category of C-check for Airbus A320.

- To improve the results positively, both manufacturers and operators should improve all of the maintenance procedures environmentally. This improvement should be prioritized as ATA100 categories are listed under system, powerplant, and structure, respectively.

Ethical approval

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

Airbus, Global Market Forecast 2019-2038. Technical report, Airbus, 2019. Available online: https://www.airbus.com/aircraft/market/global-market-forecast.html (accessed on 12.10.2020).
Aircraft Maintenance Manual (AMM) of Airbus A320, Flight Data Recording Parameter Library (FDRPL), Airbus, (2004).
Aircraft Maintenance Manual 737-300/400/500. - Seattle, Washington, USA: Boeing Commercial Airplanes group, (1999).
Altuntas, O. and Karakoc, T.H. Investigation of the environmental concern in aircraft selection for domestic flights in some Turkish airports. Journal of Aeronautics and Space Technologies 2011, 5(1), 11-18.
Altuntas, O. Calculation of domestic flight-caused global warming potential from aircraft emissions in Turkish airports. International Journal of Global Warming 2014, 6(4), 367-379.
Altuntas, O. Lead emissions from the use of leaded avgas in Turkey. Aircraft Engineering and Aerospace Technology, 2021, 93(3), 493-501.
Altuntas, O., Karakoc, T.H. and Hepbaşlı, A. Investigation of environmental impact caused by aircraft engines. International Journal of Global Warming 2013, 5(3), 282-295.
Altuntas, O., Sohret, Y. and Karakoc, T.H. Fundamentals of Sustainability. In Sustainable Aviation, 1st ed.; Karakoc, T.H., Colpan, C.O., Altuntas, O., Sohret, Y.; Springer: Springer Nature Switzerland AG, 2019; ISBN: 978-3-030-14195-0. pp.3-5.
Atak, A. and Kingma, S. Safety culture in an Aircraft Maintenance Organization: A View from the Inside. Safety Science 2011, 49, 268-278.
Boeing, Commercial Market Outlook, 2019-2038. Technical report, Boeing, 2019. Available online: https://www.boeing.com/commercial/market/commercial-market-outlook/ (accessed on 23.10.2020).
Ceruti, A., Marzocca, P., Liverani, A., and Bil, C. (2019), Maintenance in aeronautics in an Industry 4.0 context: The role of Augmented Reality and Additive Manufacturing, Journal of Computational Design and Engineering, Vol. 6 No.4, pp.516-526.
Cleveland, C.J. Encyclopedia of Energy, Elsevier Academic Press, USA, 2004.
Crocker, D., Dictionary of Aviation, A & C Black, London, 2007.
Dekker, R. and Scarf, P. A. On the impact of optimization models in maintenance decision making: the state of the art. Reliability Engineering & System Safety 1998, 60(2), 111-119.
Dijkstra, M. C., Kroon, L. G., Salomon, M., van Nunen, J. A. and van Wassenhove, L. N. Planning the Size and

Organization of KLM's Aircraft Maintenance Personnel. Interfaces 1994, 24(6), 47-58.

Ezhilarasu, C. M., Skaf, Z., and Jennions, I. K. (2019), The application of reasoning to aerospace Integrated Vehicle Health Management (IVHM): Challenges and opportunities, Progress in Aerospace Sciences, Vol. 105, pp.60-73.

Fang, L. and Zhaodong, H. System Dynamics Based Simulation Approach on Corrective Maintenance Cost of Aviation Equipments. Procedia Engineering 2015, 99, 150-155.

Fedotova, A., Taratoukhine, V., Ovsyannikov, M., and Becker, J. (2013), Implementation of constraints satisfaction problems methods for solving the periodic maintenance processes scheduling, IFAC Proceedings Volumes, Vol. 46 No. 9, pp.341-346.

Friend, C. H. Aircraft Maintenance Management. Longman Group UK. Ltd., United Kingdom, 1992.

Goedkoop, M. and Spriensma, R. The Eco-indicator 99—a damage-oriented method for life cycle assessment. Methodology Report, PRé Consultants B.V, 2000.

Gopalan, R. The Aircraft Maintenance Base Location Problem. European Journal of Operational Research 2014, 236, 634-642.

Gray, D. A. Airworthy: Decision Support for Aircraft Overhaul Maintenance Planning, OR/MS Today 1992, 24-29.

Iwata, C., and Mavris, D. (2013), Object-oriented discrete event simulation modeling environment for aerospace vehicle maintenance and logistics process, Procedia Computer Science, Vol. 16, pp.187-196.

Kafali, H. and Altuntas, O. The analysis of emission values from commercial flights at Dalaman international airport Turkey, Aircraft Engineering and Aerospace Technology 2020, 92-10,1451-1457

Kafalı, H. and Tunca, E. Importance of Maintenance Planning in Aircraft Maintenance. International Engineering and Natural Sciences Conference (IENSC 2019), Dicle University, Diyarbakır, Turkey, 6-8 November 2019.

Kala, M., Lalis, A. and Vojtech, T. Analyzing Aircraft Maintenance Findings with Natural Language Processing, Transportation Research Procedia, 2022, 65, 238-245.

Keivanpour S. and Kadi, D.A. A Sustainable Approach to Aircraft Engine Maintenance. International Federation of Automatic Control (IFAC) 2015, 48-3, 977-982.

Kinnison- H. A. and Siddiqui, T. Aviation Maintenance Management, McGraw-Hill Companies Inc., USA, 2013.

Knotts, R.M.H.., Civil aircraft maintenance and support fault diagnosis from a business perspective. Journal of Quality in Maintenance Engineering 1999, 5- 4, 335-348.

Lestiani, M.E., Yudoko, G. and Purboyo, Y. Developing a Conceptual Model of Organiztional Safety Risk: Case Studies of Aircraft Maintenance Organizations in Indonesia. Transportation Research Procedia 2017, 25, 136-148.

Lin, L., Lou, B. and Zhong, S. Development and Application of Maintenance Decision Making Support System for Aircraft Fleet. Advances in Engineering Software, 2017, 000, 1-16.

Ma, H.L., Sun, Y., Chung, S.H., and Chan, H.K. (2022), Tackling uncertainties in aircraft maintenance routing: A review of emerging Technologies, Transportation Research Part E: Logistics and Transportation Review, Vol. 164, pp.102805.

Mascle, C., Baptiste, P., Sainte Beuve, D., and Camelot, A. (2015). Process for advanced management and technologies of aircraft EOL. Procedia CIRP, 26, 299-304.

Muchiri, K.A. Maintenance Planning Optimization for the Boeing 737 Next Generation, M.Sc. thesis, Delft University of Technology, Delft, NL, 2002.

Papakoustas, N., Papachatakis, P., Xanthakis, V., Mourtzis, D. and Chryssolouris, G. An Approach to Operational Aircraft Maintenance Planning. Decision Support Systems 2010, 48,604-612.

Pintelon, L. and Muchiri, P.N. Safety and Maintenance, In Handbook of Maintenance Management and Engineering, Ben-Daya, M., Duffuaa, S.O., Raouf, A., Knezevic, J., Ait-Kadi, D., Springer-Verlag London Limited: UK, 2009; pp. 613-646.

PRéConsultant (2019). SimaPro Software, version 7.3, PRé Consultants, (https://simapro.com/).

Saltzman, R. M., and Stern, H. I. (2022), The multi-day aircraft maintenance routing problem, Journal of Air Transport Management, Vol. 102, pp.102224.

Sanderson, D., Turner, A., Shires, E., Chaplin, J.C., and Ratchev, S. (2020), Implementing large-scale aerospace assembly 4.0 demonstration systems, IFAC-PapersOnLine, Vol. 53 No.2, pp.10267-10274.

Saranga, H. and Kumar, U. D. Optimization of Aircraft Maintenance/Support Infrastructure Using Genetic Algorithms Level of Repair Analysis. Annals of Operations Research 2006, 143(1), 91-106.

Shanmugam, A. and Robert, T.P. Ranking of Aircraft Maintence Organization Based on Human Factor Performance, Computer and Industrial Engineering 2015, 88, 410-416.

Shaukat, S., Katscher, M., Wu, C.L., Delgado, F., and Larrain, H. (2020), Aircraft line maintenance scheduling and optimisation, Journal of Air Transport Management, Vol. 89, pp. 101914.

Sürekli Uçuşa Elverişlilik ve Bakım Sorumluluğu Talimatı (SHT-M Rev.03), Ankara: Directiorate General of Civil Aviation (DGCA), 2018.

Tanaka, Y., Nagai, S., Ushida, M. and Usui, T. Large Engine Maintenance Technique to Support Flight Operation for Commercial Airlines. Mitsubishi Heavy Industries Technical Review 2003, 40(2), 5-6.

US Environmental Protection Agency, EPA Office of Compliance Sector Notebook Project: Air Transportation Industry, 1998. Available online: http://purl.access.gpo.gov/GPO/LPS645

van Rijn, C. F. H., van Aken, J. A., Smit, A. C. J. M. Emma, A Maintenance Manning Assessment Tool. In Proceedings 3rd. EsReDa Seminar on Equipment Ageing and Maintenance 1992, 1, 14-15.

Verhoeff, M., Verhagen, W.J.C., and Curran, R. (2015), Maximizing operational readiness in military aviation by optimizing flight and maintenance planning, Transportation Research Procedia, Vol. 10, pp.941-950.

Wang, Y., Gogu, C., Binaud, N., Bes, C., Haftka, T.T. and Kim, N.H. A Cost Driven Predictive Maintenance Policy for Structural Airframe Maintenance. Chinese Journal of Aeronautics 2017, 30, 1242-1257.

Wen, X., Sun, X., Ma, H. and Sun, Y. A Column Generation Approach for Operational Flight Scheduling and Aircraft

Maintenance Routing, Journal of Air Transport Management 2022, 105, 1-11.

Witteman, M., Deng, Q., and Santos, B. F. (2021). A bin packing approach to solve the aircraft maintenance task allocation problem. European Journal of Operational Research, 294(1), 365-376.

Yadav, D.K. Licensing and Recognition of the Aircraft Maintenance Engineers – A Comparative Study. Journal of Air Transport Management 2010, 16, 272-278.

Yang, Z. and Yang, G.; Optimization of Aircraft Maintenance Plan Based on Genetic Algorithm. Physics Procedia 2012, 33, 580-586.

Yu, J. and Gulliver, S. Improving aircraft maintenance, repair, and overhaul: A novel text mining approach. International Conference on Intelligent Computing and Intelligent Systems, Guangzhou, China, 2011.

Yu, T., Zhu, C., Chang, Q., and Wang, J. (2019), Imperfect corrective maintenance scheduling for energy efficient manufacturing systems through online task allocation method, Journal of Manufacturing Systems, Vol. 53, pp.282-290.

Cite this article: Kafalı, H. (2024). Assessing the Environmetnal Impact of Aircraft Maintenance. Journal of Aviation, 8(1), 7-14.