Norbert GRZESIK
Polish Air Force University
e-mail: n.grzesik@law.mil.pl; ORCID: 0000-0001-9932-4459

Michał JASZTAL
Military University of Technology
e-mail: michal.jasztal@wat.edu.pl; ORCID: 0000-0003-4133-2557

Magdalena HEZNER
Polish Air Force University
e-mail: m.hezner@law.mil.pl

Witold SARNOWSKI
Polish Air Force University
e-mail: w.sarnowski@law.mil.pl; ORCID: 0000-0002-7606-7741

Marta WOCH
Air Force Institute of Technology
e-mail: marta.woch@itwl.pl; ORCID: 0000-0003-4872-0720

DOI: 10.55676/asi.v4i2.88

ANALYSIS OF AVIATION INCINDENTS OCCURRING ON THE SW-4 HELICOPTER IN THE YEARS 2010–2020

ANALIZA ZDARZEŃ LOTNICZYCH ZAISTNIAŁYCH NA ŚMIGŁOWCU SW-4 W LATACH 2010–2020

Abstract

This paper presents the issue of aviation incidents on the SW-4 helicopter from 2010 to 2020. Increasing the level of reliability and maintaining the highest possible efficiency of aviation equipment should be preceded by an extensive analysis of former incidents. In this paper was conducted a division delineating the factors influencing the occurrence of incidents on the SW-4 helicopter, detailing the most common faults. A reliability analysis was conducted for each year of the helicopter's utilization. Finally, conclusions were drawn that can provide a basis for improving the level of operation.

Keywords: safety, aviation incidents, reliability, helicopter

Streszczenie

W artykule przedstawiono zagadnienie zdarzeń lotniczych na śmigłowcu SW-4 w latach 2010–2020. Wzrost poziomu niezawodności oraz utrzymanie możliwie najwyższej sprawności sprzętu lotniczego powinno zostać poprzedzone obszerną analizą dotychczasowych incydentów. W pracy dokonano podziału na poszczególne czynniki sprawcze wpływające na powstanie incydentów na śmigłowcu SW-4 z wyszczególnieniem najczęstszych usterek. Przeprowadzono analizę niezawodnościową w poszczególnych latach eksploatacji śmigłowca. Na zakończenie wyciągnięto wnioski mogące stanowić podstawę do poprawienia poziomu eksploatacji.

Słowa kluczowe: bezpieczeństwo, incydenty lotnicze, niezawodność, SW-4 „Puszczyk”

Artykuł wpłynął do redakcji: 19.09.2023 / Zatwierdzono do publikacji: 30.12.2023

1. INTRODUCTION

Aircraft are one of the safest modes of transport. However, despite their high level of safety, they are subject to unforeseen events that can reduce the level of safety. Unlike civil aircraft, military helicopters are also used in armed conflicts, where the prevailing conditions are conducive to damage. Military helicopters are most often used to fly at low altitudes over terrain in adverse weather conditions. During flight, the speed and direction of flight, as well as the helicopter's altitude, often change. In such demanding flight conditions, the failure of the power unit may result in autorotation, which, due to the low vertical distance from the ground, may not produce the desired results.

Increasing flight safety is possible using appropriate design solutions to improve the efficiency of the aircraft. For this purpose, an analysis of past failures is used. Investigating the causes of aviation incidents allows conclusions to be drawn and appropriate procedures to be implemented to prevent similar situations from occurring in the future.

2. LITERATURE REVIEW

2.1. FACTORS INFLUENCING SAFETY IN HELICOPTER OPERATIONS

Helicopters play a crucial role in various operations, including emergency medical services, search and rescue missions, offshore transportation, and military activities. However, the aviation industry faces challenges related to safety incidents and accidents involving helicopters. Understanding the factors contributing to these incidents is essential for improving safety measures and preventing future accidents. This literature review aims to analyze existing research on aviation incidents occurring on helicopters to identify common causes, contributing factors, and potential mitigation strategies.

Human factors have been identified as a significant contributor to aviation accidents. The Human Factors Analysis and Classification System (HFACS) framework proposed by provides a structured approach to identifying and classifying human errors in aviation accidents[1]. By utilizing the HFACS framework, investigators can effectively analyze the human factors involved in helicopter incidents, bridging the gap between theory and practice.

Weather conditions also play a critical role in aviation safety, particularly in general aviation accidents. discuss the impact of weather on general aviation accidents and highlight the need for improved aviation weather information systems to enhance

[1] A. Scott, Shappell and Douglas A. Wiegmann, The Human Factors Analysis and Classification System (HFACS), 2017, https://doi.org/10.4324/9781315263878-3.

 DOI: 110.55676/asi.v4i2.88

pilot decision-making[2]. Similarly, 's study on weather-related general aviation accidents in the United States emphasizes the importance of increasing awareness and training to handle adverse weather conditions[3].

In the context of helicopter operations, propose a structured framework for analyzing accidents, focusing on determining the appropriate timeframe for analysis, establishing terminological definitions, and conducting statistical analyses[4]. This approach provides a comprehensive method for investigating helicopter accidents and identifying key variables that contribute to incidents.

Safety in high-risk helicopter operations, such as sling-load operations, is another area of concern. highlight the role of additional crew members in accident prevention during external-load helicopter operations[5]. Understanding the causes and circumstances of accidents in these high-risk operations is essential for implementing effective safety measures.

Mission type and pilot characteristics also influence helicopter accidents emphasize the importance of analyzing how errors identified through human error frameworks relate to pilot and flight characteristics, such as mission type[6]. By understanding the differences in helicopter mission sets, researchers can gain insights into the specific factors that contribute to human errors in different operational contexts.

Furthermore, the impact of fatigue on aviation personnel, including aircrew and ground crew, is a significant concern. assess fatigue among aviation personnel involved in military flying in India and highlight the risk factors that contribute to fatigue in aviation operations[7]. Addressing fatigue-related issues is crucial for maintaining the safety and well-being of aviation personnel.

In the context of helicopter maintenance and operations, studies have focused on assessing aircraft maintenance technician competency and the impact of outsourcing maintenance on flight safety[8]. Developing proactive methods to enhance technician competency and ensuring the quality of maintenance practices are essential for preventing maintenance-related incidents.

[2] G. Capobianco, M.D. Lee, The Role of Weather in General Aviation Accidents: An Analysis of Causes, Contributing Factors and ISSUES, Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2001, https://doi.org/10.1177/154193120104500241.

[3] A.J. Fultz, S.A. Walker, Fatal Weather-Related General Aviation Accidents in the United States, Physical Geography, 2016, https://doi.org/10.1080/02723646.2016.1211854.

[4] A. Felipe, C. Nascimento, A. Majumdar, W.Y. Ochieng, Helicopter Accident Analysis, Journal of Navigation, 2013, https://doi.org/10.1017/s037346331300057x.

[5] A. de Voogt, S. Uitdewilligen, N. Eremenko, Safety in High-Risk Helicopter Operations: The Role of Additional Crew in Accident Prevention, Safety Science, 2009, https://doi.org/10.1016/j.ssci.2008.09.009.

[6] K.A. Morowsky, K. Funk, Understanding Differences in Helicopter Mission Sets Prior to Human Error Analysis, Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2016, https://doi.org/10.1177/1541931213601330.

[7] Mohapatra Ss, Ranjan Sarkar, Dhrubajyoti Ghosh, Assessment of Fatigue Among Aviation Personnel Involved in Military Flying in India Employing Multidimensional Fatigue Symptom Inventory – Short Form (MFSI-SF), Indian Journal of Aerospace Medicine, 2020, https://doi.org/10.25259/ijasm_14_2020.

[8] Q. Commine, Outsourcing Aircraft Maintenance: What Impact on Flight Safety?, International Journal of Applied Research in Business and Management, 2023, https://doi.org/10.51137/ijarbm.2023.4.2.5.

Overall, the literature review highlights the multifaceted nature of factors contributing to aviation incidents occurring on helicopters. By examining human factors, weather conditions, mission characteristics, crew fatigue, and maintenance practices, researchers can gain a comprehensive understanding of the challenges faced in helicopter operations. Identifying these factors is crucial for developing targeted interventions and safety measures to mitigate the risks associated with helicopter incidents.

2.2. RELIABILITY IN INVESTIGATING HELICOPTER INCIDENTS

Reliability in investigating helicopter incidents is a critical aspect that underpins the effectiveness of incident analysis and the subsequent implementation of safety measures. Ensuring the reliability of investigations involves various factors, including the engagement of stakeholders such as hospital managers and incident investigators[9]. By incorporating a patient and family-centered approach, hospitals can enhance the reliability of incident investigations, leading to improved learning outcomes and patient-centered care following incidents.

Additionally, the speed and efficiency of emergency medical service (EMS) responses, including helicopter EMS, play a vital role in patient outcomes[10]. Dispatch time and on-scene time are key metrics that can impact the reliability of EMS operations and the timely delivery of patients to definitive care facilities. Moreover, the development of reliable tools to monitor helicopter pilot performance, such as the Field-Deployable Psychomotor Vigilance Test, can provide valuable data on factors like fatigue that affect operational safety[11]. By ensuring the reliability and validity of such tools, researchers can contribute to a better understanding of the human factors influencing helicopter incidents[12].

Furthermore, the optimization of search and rescue helicopter operations through models like integer programming enhances the reliability and efficiency of rescue missions, reducing response times and improving outcomes for victims[13]. Reliability in investigating helicopter incidents extends to the structural integrity of helicopters themselves, as highlighted in studies focusing on crashworthiness and composite

9 J.L. de Kok, I. Leistikow, R. Bal, Patient and Family Engagement in Incident Investigations: Exploring Hospital Manager and Incident Investigators' Experiences and Challenges, Journal of Health Services Research & Policy, 2018, https://doi.org/10.1177/1355819618788586.

10 H. Pham, Y. Puckett, S. Dissanaike, Faster On-Scene Times Associated With Decreased Mortality in Helicopter Emergency Medical Services (HEMS) Transported Trauma Patients, Trauma Surgery & Acute Care Open, 2017, https://doi.org/10.1136/tsaco-2017-000122.

11 T.W. McMahon, D.G. Newman, Development of a Field-Deployable Psychomotor Vigilance Test to Monitor Helicopter Pilot Performance, Aerospace Medicine and Human Performance, 2016, https://doi.org/10.3357/amhp.4425.2016.

12 J. Ziółkowski, J. Małachowski, M. Oszczypała, J. Szkutnik-Rogoż, J. Konwerski, Simulation model for analysis and evaluation of selected measures of the helicopter's readiness, Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace EngineeringThis link is disabled, 2022, 236(13), pp. 2751–2762.

13 M. Karatas, N. Razi, M.M. Gunal, An ILP and Simulation Model to Optimize Search and Rescue Helicopter Operations, Journal of the Operational Research Society, 2017, https://doi.org/10.1057/s41274-016-0154-7.

 DOI: 110.55676/asi.v4i2.88

materials for weight-saving and safety improvements[14]. By prioritizing reliability in incident investigations, from human factors to operational procedures and aircraft design, stakeholders can work towards enhancing the overall safety and effectiveness of helicopter operations.

3. METHODOLOGY

The subject of the study was SW-4 'Puszczyk' helicopters. The study used data from the operation process from 2010 to 2020. Based on statistical analysis, the factors that most frequently influenced the occurrence of incidents were identified.

Statistics is a research field based on observation, data acquisition and data analysis. The greater the amount of data used for analysis, the more accurate conclusions can be drawn. Statistical research can be divided into the following stages:

- Preparing for the survey, i.e. establishing the purpose, scope and method of obtaining and accumulation of information;
- statistical observation, which may be complete and deal with the whole set or partial and take into account only selected elements of the set;
- the processing and analysis of the data obtained, using selected statistical methods.

3.1. RELIABILITY MEASUREMENTS

By observing previous data on aircraft use, it may be concluded that all damage is the result of random events. On the other hand, flight hours, number of damages, number of accidents or missed assignments are random variables.

The basic function is the reliability function over time. The function $R(t)$ takes on an explicit value for the probability of a given machine not failing at a given time.

$$R(t) = P(T > t) \quad (1)$$

where:

P – probability;

T – time of correct operation.

This function is a non-increasing function if there are no additional impacts on the investigated object. Another basic measure is the unreliability function $Q(t)$, it takes the value of the event probability $T < t$ and is presented as follows[15]:

$$Q(t) = P(T < t) \quad (2)$$

Both functions (unreliability and reliability) equal unity, from which it follows that the unreliability function is non-decreasing assuming no additional impact on the object.

14 A. Al-Fatlawi, K. Jármai, G. Kovács, Optimization of a Totally Fiber-Reinforced Plastic Composite Sandwich Construction of Helicopter Floor for Weight Saving, Fuel Saving and Higher Safety, Polymers, 2021, https://doi.org/10.3390/polym13162735.

15 J. Zurek, M. Zieja, J. Ziolkowski, Reliability of Supplies in a Manufacturing Enterprise, in Safety and Reliability - Safe Societies in a Changing World, ed. S. Haugen et al. (Leiden: Crc Press-Balkema, 2018), 3143–47, https://www.webofscience.com/wos/woscc/full-record/WOS:000549917603087.

If $R(T=0)=1$ and the function is continuous then:

$$R(t)=\int_t^{\infty} f(t)dt \tag{3}$$

where:

$f(t)$ – probability distribution density of the random variable T:

$$f(t)=-\frac{d}{dt}R(t)=-R'(t) \tag{4}$$

$$f(t)=\frac{d}{dt}Q(t)=Q'(t) \tag{5}$$

The probability of damage in the time interval $[t, t+\Delta t]$ assuming that the object has not been damaged at time t can be defined as the failure rate function $\lambda(t)$. It describes the reduction in reliability per unit time Δt. Reliability is related to the density function of the random variable T:

$$\lambda(t)=\frac{P(t,\Delta t)}{\Delta t}=\frac{\frac{f(t)}{R(t)}\Delta t}{\Delta t}=\frac{f(t)}{R(t)} \tag{6}$$

From the waveform of the function, the following can be determined:

The cumulative hazard function of the distribution:

$$\Lambda(t)=\int_0^t \lambda(x)dx \tag{7}$$

The reliability function:

$$R(t)=P(T\geq t)=\exp\left[-\int_0^t \lambda(x)dx\right]=\exp[-\Lambda(t)] \tag{8}$$

The unreliability function:

$$Q(t)=P(T<t)=1-R(t)=1-\exp\left[-\int_0^t \lambda(x)dx\right]=1-\exp[-\Lambda(t)] \tag{9}$$

The probability density function:

$$f(t)=\frac{dF(t)}{dt}=\lambda(t)\exp\left[-\int_0^t \lambda(x)dx\right]=\frac{d}{dt}\{\exp[-\Lambda(t)]\} \tag{10}$$

3.2. EXPLANATION OF STATISTICAL METHODS AND TOOLS USED IN THE ANALYSIS

The statistical analysis conducted in this study involves several key stages, employing both descriptive and inferential statistical methods to interpret the data on aviation incidents related to the SW-4 helicopter. Initially, data was gathered and organized into categories based on the type of incident, contributing factors, and the year of occurrence. Descriptive statistics, such as frequencies and percentages, were utilized to summarize the data, providing an overview of incident trends over the study period from 2010 to 2020.

 DOI: 110.55676/asi.v4i2.88

To further delve into the reliability and failure rates of the helicopter, the study employed reliability function $R(t)$ and failure rate function $\lambda(t)$ calculations. These functions were used to model the time until failure of the helicopter components, offering insights into the operational dependability of the SW-4. Microsoft Excel was the primary software used for this analysis, chosen for its robust data handling capabilities and advanced statistical functions. Excel facilitated the creation of detailed graphs and tables that visually represent the reliability and failure trends over time.

Additionally, the study applied survival analysis techniques, including Kaplan-Meier estimators, to better understand the probability of component failures over specified time intervals. By using these statistical methods and tools, the study provides a comprehensive analysis of the factors influencing aviation incidents, thereby supporting the development of targeted safety and maintenance strategies.

3.3. ANALYSIS OF AVIATION INCIDENTS

Using data collected from the operation of SW-4 helicopters over the years 2010 to 2020, an analysis was carried out to illustrate the background to the occurrence of aviation incidents. Aviation incidents usually occur because of a number of interconnected causes, which separately may be seemingly insignificant. These causes are called causal or failure factors, which can be divided into three groups: human, technical and environmental factors. The human factor relates only to the flying personnel, but aspects of this factor also relate to technical, environmental and organisational areas. The technical factor relates to the components and systems of the aircraft within the context of airworthiness. The environmental factor refers to the conditions under which the aircraft is flown and the equipment responsible for flight safety[16].

In the cases analysed, the most common factor contributing to incidents was technical. Therefore, it was further analysed in terms of the occurrence of recurrent helicopter faults. The human factor consisted of errors in the operation of the aircraft such as exceeding operating limitations. The environmental factor, on the other hand, is related to collisions with birds, as well as the negative impact of weather conditions on the helicopter's fuselage[17].

The first stage of the research involved an analysis of the causal factors influencing the occurrence of incidents on the SW-4 helicopter in each year of operation. The results of the analysis are presented in Table 1.

16 M. Zieja, H. Smoliński, P. Gołda, Information Systems as a Tool for Supporting the Management of Aircraft Flight Safety, Archives of Transport 36 (2015).

17 P. Gołda, J. Manerowski, Model Systemu Operacji Kołowania Samolotów, Logistyka 3 (2014): 7240–46.

Table 1. Causal factors of incidents on SW-4 between 2010 and 2020

	Technical factor	Environmental factor	Human factor
2010	96% (79)	1% (1)	3% (2)
2011	94% (66)	2% (1)	4% (3)
2012	94% (135)	4% (5)	2% (3)
2013	96% (76)	0%	4% (3)
2014	93% (55)	5% (3)	2% (1)
2015	98% (90)	2% (2)	0%
2016	92% (69)	1% (1)	7% (5)
2017	94% (50)	2% (1)	4% (2)
2018	100% (31)	0%	0%
2019	98% (61)	0%	3% (2)
2020	97% (56)	0%	3% (2)

Source: own study.

Based on the analysis, technical faults were the main cause of incidents on the SW-4 helicopter in 2010. Human and environmental factors were the cause of two and one incident respectively. Based on the analysis, it is noted that in 2011 the human and environmental factor had a negligible impact on the occurrence of incidents compared to the technical factor, which accounted for 94%. In 2012, technical faults were the main cause of incidents on the 'Puszczyk'. Human error was reported on three occasions, while the environment influenced 5 incidents. In contrast, in 2013 there was no incident affected by the environmental factor, the human factor was responsible for 3 (4%) and the technical factor for 96% of incidents.

The analysis showed that in 2014, the human and environmental factor accounted for 7% of incidents and the technical factor for 93%. In 2015, humans did not contribute to any incidents, while an environmental factor was the cause of two. The technical factor influenced 98% of the incidents that occurred. The analysis shows that in 2016, the human factor had a greater impact on incidents arising than in previous years and contributed to 7% of incidents, where the environmental factor was the cause in one case and the technical factor in 69 (92%). Based on the analysis, in 2017, the human factor and the environmental factor caused 3 incidents and the technical factor caused 50 incidents (94%). In 2018, all incidents were due to a technical factor. In 2019, the environmental factor was not the cause of any incident and the human factor caused 2 incidents. The technical factor was responsible for 97% of incidents. The study shows that in 2020, the environmental factor was also not the cause of any incident, the human factor contributed to 2 incidents and the technical factor to 56 (97%).

The next stage is an analysis of the percentage of faults. A summary of the occurrence of the given fault groups on the SW-4 'Puszczyk' helicopter is presented in Table 2.

DOI: 110.55676/asi.v4i2.88

Table 2. Percentage of selected faults on SW-4 between 2010 and 2020

	Clutch filings	Engine filings	Torque fluctuations	Filing gear	Heading system	Artificial horizon	Other
2010	18% (14)	20% (16)	9% (7)	0%	1% (1)	5% (4)	47% (37)
2011	18% (12)	11% (7)	18% (12)	0%	0%	5% (3)	48% (32)
2012	12% (17)	7% (9)	41% (55)	1% (1)	0%	5% (7)	34% (46)
2013	11% (8)	21% (16)	14% (11)	3% (2)	0%	4% (3)	47% (36)
2014	11% (6)	9% (5)	18% (10)	0%	0%	6% (3)	56% (31)
2015	11% (10)	10% (9)	13% (12)	0%	0%	11% (10)	55% (49)
2016	28% (19)	17% (12)	12% (8)	0%	0%	1% (1)	42% (29)
2017	14% (7)	2% (1)	10% (5)	0%	6% (3)	6% (3)	62% (31)
2018	3% (1)	3% (1)	0%	3% (1)	26% (8)	13% (4)	52% (16)
2019	8% (5)	13% (8)	2% (1)	2% (1)	6% (4)	7% (4)	62% (38)
2020	0%	2% (1)	3% (2)	11% (6)	5% (3)	2% (1)	77% (43)

Source: own study.

The analysis shows that in 2010, faults involving engine and clutch filing represented 38% of all faults. In 2011, it can be seen that there was an increased proportion of faults involving torque meter fluctuation, which occurred as frequently as clutch filing, or 18%. In 2012, torque meter fluctuation accounted for the largest part of faults and accounted for 41% of cases, corresponding to 55 incidents caused by this fault. The analysis shows that in 2013, faults related to engine filing and clutch and torque meter fluctuations accounted for 46% of all faults. In 2014, torque meter fluctuations accounted for the largest percentage of recurring technical faults, while clutch and engine filing together accounted for 20 per cent of faults. In 2015, artificial horizon faults, torque meter fluctuations and engine and clutch filing occurred with similar frequencies of several percent each. The analysis shows that in 2016, clutch filing occurred as many as 19 times, accounting for 28% of all technical faults, and together with engine filing and torque meter fluctuations contributed to more than half (57%) of the incidents. The most common fault in 2017 was clutch filing. This year, recurring faults accounted for only 38% of all incidents. The same situation also occurred in 2019. Clutch, engine and transmission filing occurred exactly once each in 2018. Course system-related faults were noticeably more frequent and accounted for 26%. This year, the "Puszczyk" had the smallest number of flight hours of the years analysed and the fewest incidents (31). Based on the analysis, 2019, like 2017, was very diverse in terms of faults that occurred. Engine filing was the most common and, together with clutch filing, contributed to 21% of incidents. In 2020, transmission filing occurred 6 times and this is the highest figure of the period analysed. This was the most diverse year in terms of the type of faults occurring. Specified contributed only 23% of all incidents.

The next stage of the research involved analysing reliability, unreliability and failure rate as a function of time. Table 3 shows the flight hours and number of incidents per year.

Table 3. Number of flight hours and number of incidents on SW-4 helicopter

	Flight hours [h]	Incidents
2010	3264	82
2011	3136	70
2012	3389	143
2013	2155	79
2014	2135	59
2015	2916	90
2016	3155	75
2017	2828	53
2018	1815	31
2019	2619	63
2020	2283	56

Source: own study.

In the next step, failure and reliability graphs were calculated and generated. Microsoft Excel was used for this purpose.

In 2010, the number of incidents was 82 with a flight hours of 3264, therefore:

$$\Lambda_{SW-4\ 2010} = \frac{82}{3264} = 0,025122\frac{1}{h} \quad (11)$$

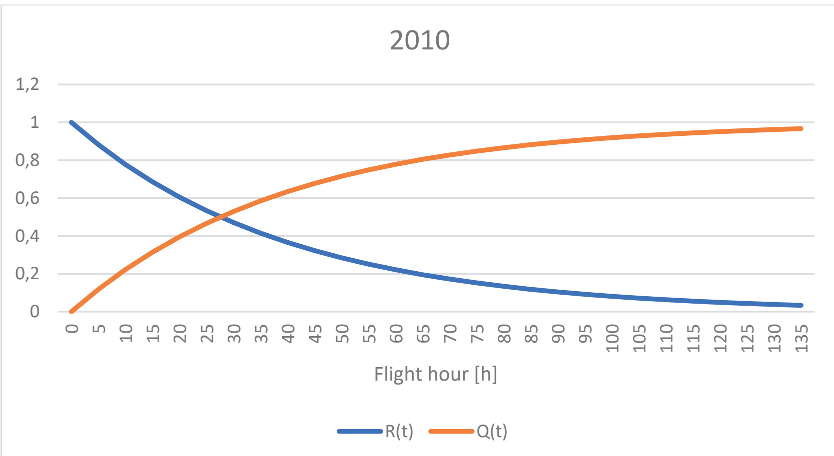

Fig. 1. Reliability and dependability as a function of the flight hours for the SW-4 in 2010

Source: own study.

In 2011, the number of incidents was 70 with a flight hours of 3136, therefore:

$$\Lambda_{SW-4\ 2011} = \frac{70}{3136} = 0,022321\frac{1}{h} \quad (12)$$

 DOI: 110.55676/asi.v4i2.88

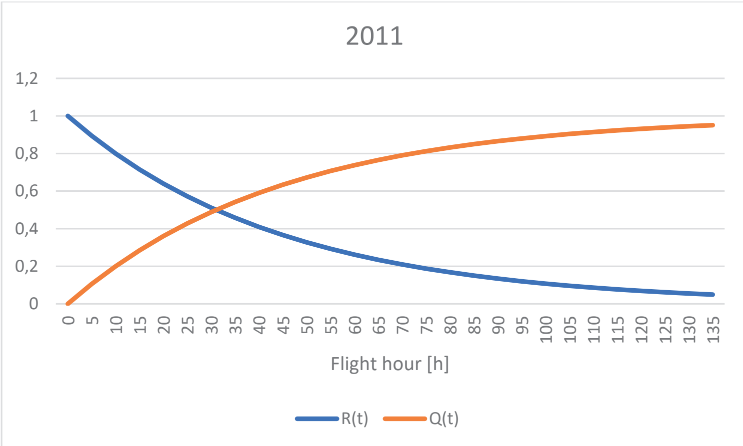

Fig. 2. Reliability and dependability as a function of the flight hours for the SW-4 in 2011
Source: own study.

In 2012, the number of incidents was 143 with a flight hours of 3389, therefore:

$$\Lambda_{SW-4\ 2012} = \frac{143}{3389} = 0,042195 \frac{1}{h} \tag{13}$$

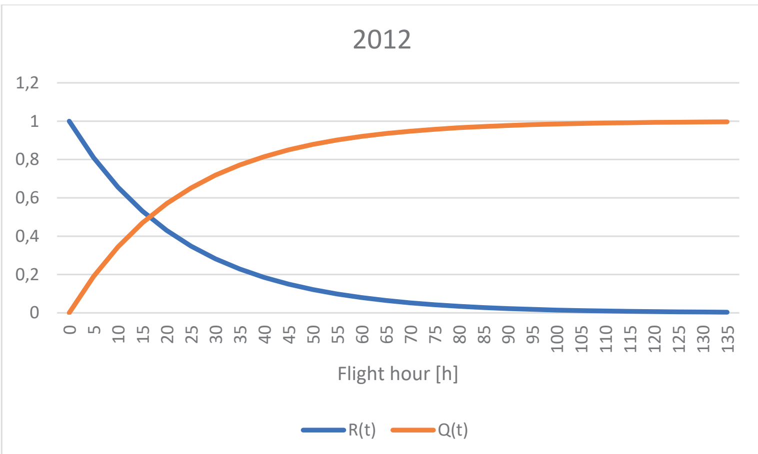

Fig. 3. Reliability and dependability as a function of the flight hours for the SW-4 in 2012
Source: own study.

In 2013, the number of incidents was 79 with a flight hours of 2155, therefore:

$$\Lambda_{SW-4\ 2013} = \frac{79}{2155} = 0,036658 \frac{1}{h} \tag{14}$$

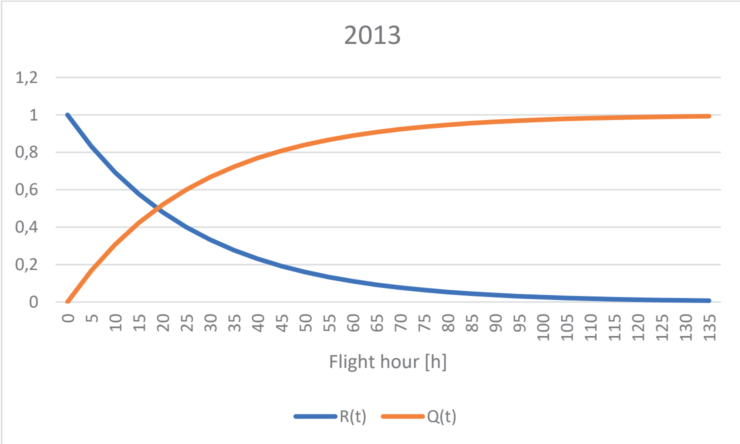

Fig. 4. Reliability and dependability as a function of the flight hours for the SW-4 in 2013
Source: own study.

In 2014, the number of incidents was 59 with a flight hours of 2135, therefore:

$$\Lambda_{SW-4\ 2014} = \frac{59}{2135} = 0,027634\frac{1}{h} \tag{15}$$

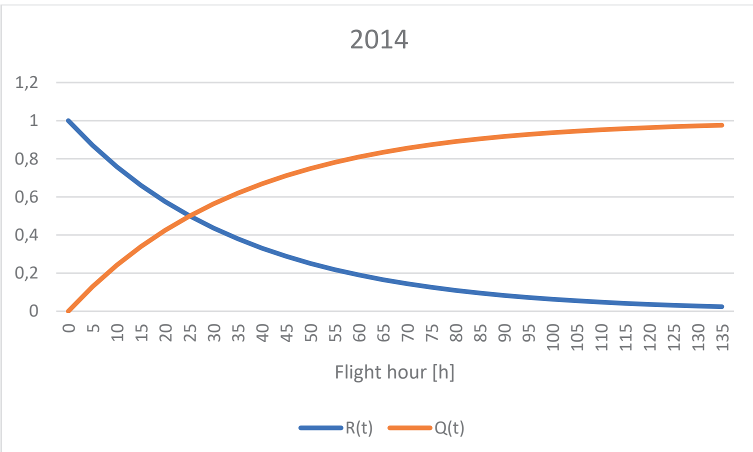

Fig. 5. Reliability and dependability as a function of the flight hours for the SW-4 in 2014
Source: own study.

In 2015, the number of incidents was 90 with a flight hours of 2916, therefore:

$$\Lambda_{SW-4\ 2015} = \frac{90}{2916} = 0,030864\frac{1}{h} \tag{16}$$

DOI: 110.55676/asi.v4i2.88

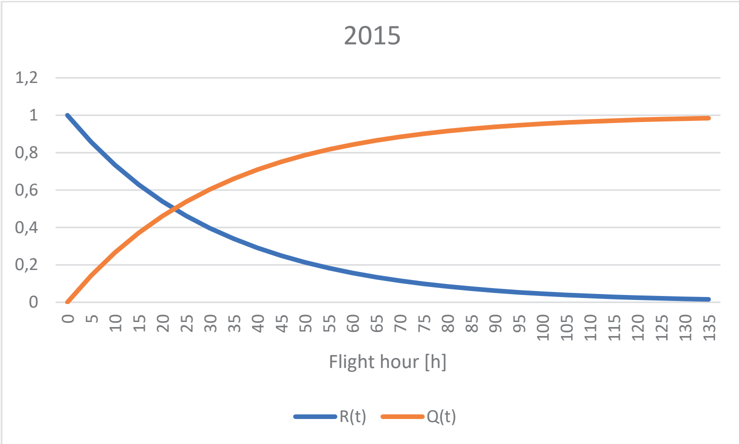

Fig. 6. Reliability and dependability as a function of the flight hours for the SW-4 in 2015
Source: own study.

In 2016, the number of incidents was 75 with a flight hours of 3155, therefore:

$$\Lambda_{SW-4\ 2016} = \frac{75}{3155} = 0{,}023771\frac{1}{h} \tag{17}$$

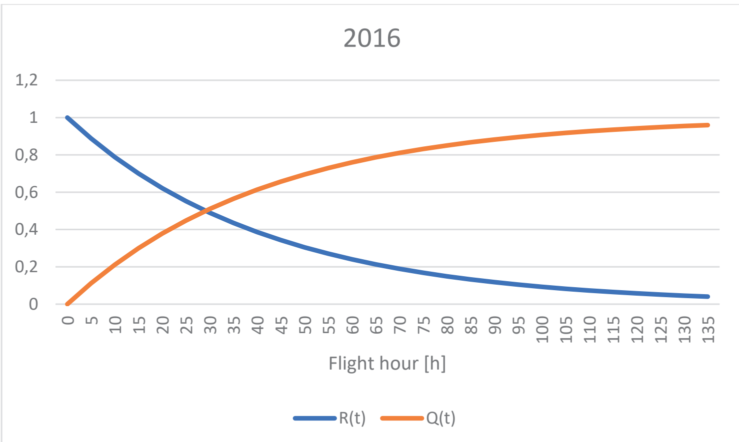

Fig. 7. Reliability and dependability as a function of the flight hours for the SW-4 in 2016
Source: own study.

In 2017, the number of incidents was 53 with a flight hours of 2828, therefore:

$$\Lambda_{SW-4\ 2017} = \frac{53}{2828} = 0{,}018741\frac{1}{h} \tag{18}$$

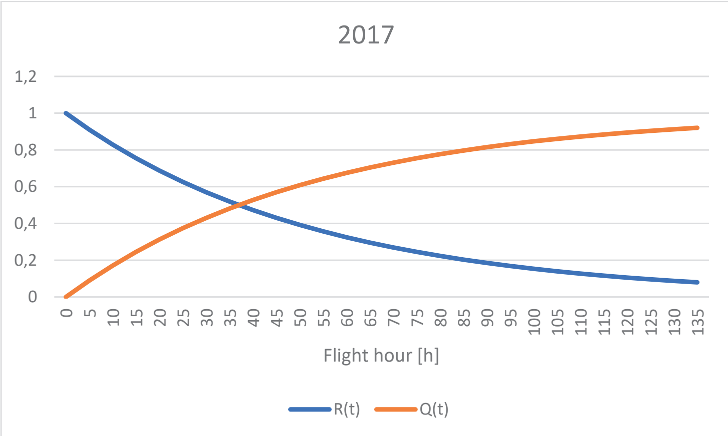

Fig. 8. Reliability and dependability as a function of the flight hours for the SW-4 in 2017
Source: own study.

In 2018, the number of incidents was 31 with a flight hours of 1818, therefore:

$$\Lambda_{SW-4\ 2018} = \frac{31}{1815} = 0,017079 \frac{1}{h} \tag{19}$$

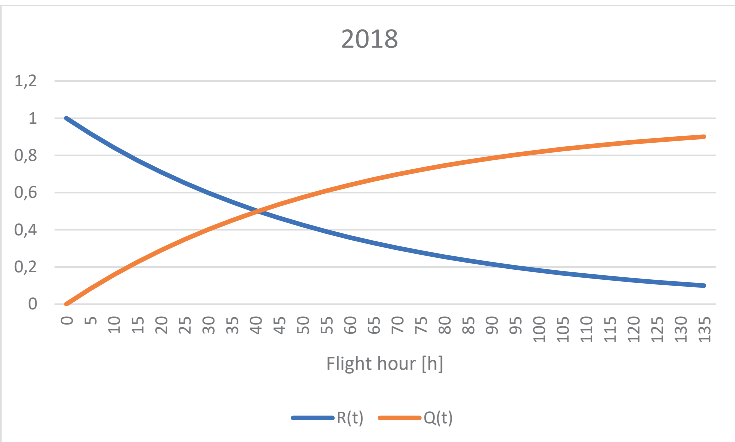

Fig. 9. Reliability and dependability as a function of the flight hours for the SW-4 in 2018
Source: own study.

In 2019, the number of incidents was 63 with a flight hours of 2619, therefore:

$$\Lambda_{SW-4\ 2019} = \frac{63}{2619} = 0,024054 \frac{1}{h} \tag{20}$$

DOI: 110.55676/asi.v4i2.88

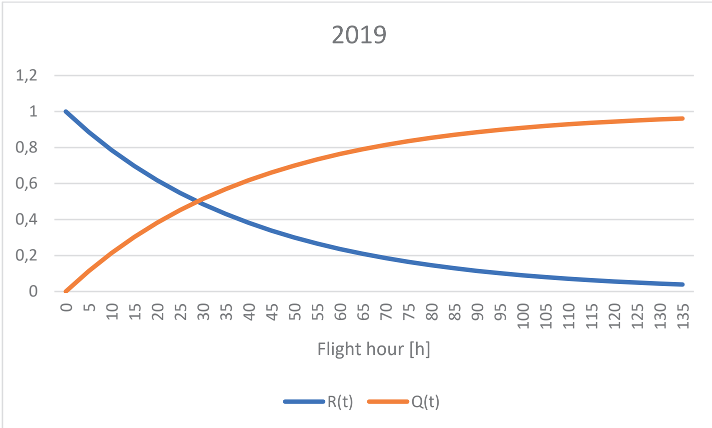

Fig. 10. Reliability and dependability as a function of the flight hours for the SW-4 in 2019
Source: own study.

In 2020, the number of incidents was 56 with a flight hours of 2283, therefore:

$$\Lambda_{SW-4\ 2020} = \frac{56}{2283} = 0,024529 \frac{1}{h} \tag{21}$$

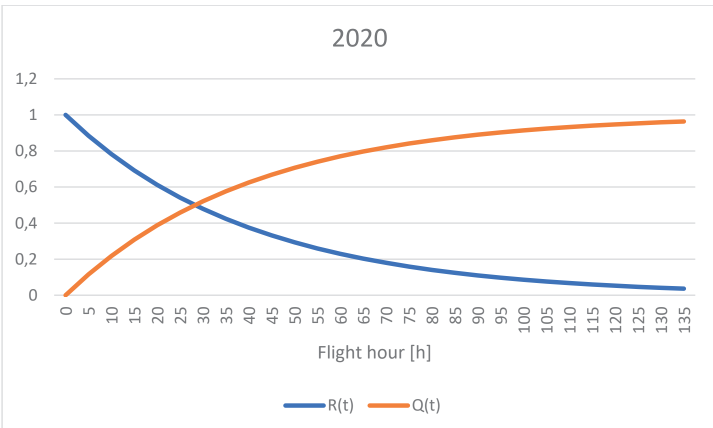

Fig. 11. Reliability and dependability as a function of the flight hours for the SW-4 in 2020
Source: own study.

An analysis of damage intensity was subsequently carried out:

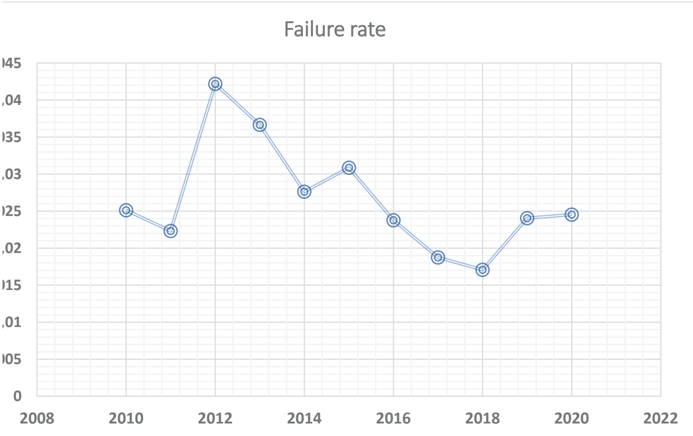

Fig. 12. Changes and increments in failure rate on SW-4 between 2010 and 2020
Source: own study.

Table 4. Changes and increments in failure rate on SW-4 from 2010 to 2020

	Failure rate	Annual increment	Relative increment
2010	0.025		
2011	0.022	88.850	88.850
2012	0.042	189.037	167.960
2013	0.037	86.877	145.920
2014	0.028	75.383	109.999
2015	0.031	111.689	122.856
2016	0.024	77.018	94.622
2017	0.019	78.839	74.600
2018	0.017	91.132	67.984
2019	0.024	140.839	95.749
2020	0.024	101.975	97.639

Source: own study.

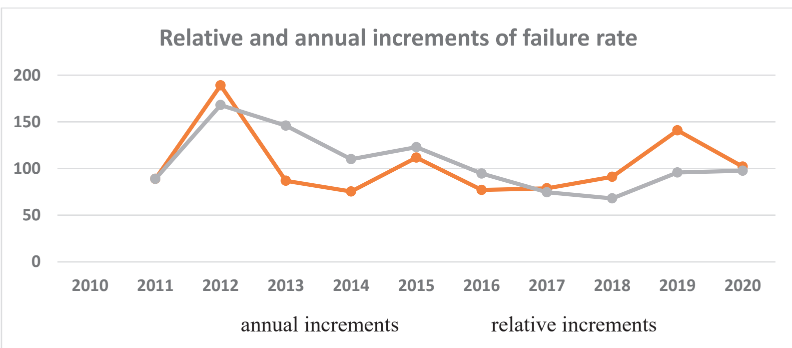

Fig. 13. Relative and annual increments of failure rate on SW-4 from 2010 to 2020
Source: own study.

DOI: 110.55676/asi.v4i2.88

Based on the data from the calculations in Tab. 4 was generated the course of the relative and annual increment of the failure rate on the SW-4 helicopter from 2010 to 2020. The failure rate, after a sharp increase in 2012 to 0.042 1/h, declined regularly to the lowest recorded value in 2018, namely 0.017 1/h, before stabilising around 0.025 1/h. The helicopter achieved its highest reliability in 2018, however, it must be taken into account that 1815 hours were performed on it, i.e. the fewest in the analysed period. In 2017, reliability was at a marginally lower level however, with a noticeably higher flight hours of 2828.

4. ACTIONABLE RECOMMENDATIONS BASED ON ANALYSIS

Based on the comprehensive analysis of aviation incidents involving the SW-4 helicopter from 2010 to 2020, several actionable recommendations have been identified. These recommendations aim to enhance safety, improve maintenance practices, and guide future research to mitigate the occurrence of similar incidents.

Policy Changes:

1. Standardization of Incident Reporting: Implement a standardized incident reporting system across all units operating SW-4 helicopters. This system should ensure detailed and consistent documentation of each incident, including contributing factors and outcomes. Such standardization will facilitate more accurate data collection and analysis, aiding in the identification of recurring issues and trends.
2. Enhanced Training Programs: Develop and mandate comprehensive training programs focusing on the specific operational challenges and technical nuances of the SW-4 helicopter. These programs should include regular refresher courses on emergency procedures, handling adverse weather conditions, and managing low-altitude flights. Emphasizing the importance of adherence to operational limits and protocols will reduce human error incidents.

Improvements in Maintenance Practices:

1. Proactive Maintenance Scheduling: Shift from reactive to proactive maintenance strategies by implementing predictive maintenance schedules. Utilize data analytics to predict potential failures based on historical incident data and perform maintenance before issues arise. This approach will help in identifying and rectifying faults such as clutch filings, engine filings, and torque fluctuations before they result in incidents.
2. Regular Audits and Inspections: Conduct regular audits and inspections of maintenance procedures to ensure compliance with safety standards. These audits should include thorough checks of all helicopter systems, with a particular focus on components that have shown higher failure rates, such as the heading system and artificial horizon. Implementing stringent inspection protocols will enhance the overall reliability of the helicopter.

Areas for Further Research:

1. Human Factors Analysis: Undertake in-depth studies on the human factors contributing to SW-4 incidents. Research should focus on understanding the cognitive

and physical demands placed on pilots and maintenance personnel, identifying common errors, and developing strategies to mitigate these errors. Incorporating findings from the Human Factors Analysis and Classification System (HFACS) can provide valuable insights into human error prevention.

2. Impact of Environmental Conditions: Explore the effects of various environmental conditions on SW-4 helicopter performance. Research should examine how factors such as weather, terrain, and bird strikes contribute to incidents and develop strategies to mitigate these risks. This could include advancements in weather forecasting technologies and the development of more robust collision avoidance systems.
3. Advancements in Helicopter Technology: Invest in research and development of advanced technologies to enhance the safety and reliability of the SW-4 helicopter. This includes exploring the use of composite materials for weight-saving and crashworthiness, as well as the development of more efficient and reliable power units. Collaborating with aerospace engineers and technology firms can lead to significant improvements in helicopter design and performance.

By implementing these recommendations, the operational safety and reliability of the SW-4 helicopter can be significantly improved. Continuous monitoring, evaluation, and adaptation of these strategies will ensure that the highest standards of aviation safety are maintained, ultimately reducing the occurrence of aviation incidents and enhancing the overall efficiency of helicopter operations.

5. CONCLUSIONS

The qualitative analysis showed which human, technical or environmental factor caused the highest number of incidents. The analysis shows that throughout the period from 2010 to 2020, it was the technical factor. It was the cause of the vast majority of incidents. In each year, it was present in more than 90% of incidents. Due to this high proportion of the technical factor, it was analysed quantitatively. The most frequently occurring technical faults were selected from the available data: the occurrence of filing in the engine, clutch, gearbox, torque meter fluctuations, artificial horizon faults and erroneous course system readings.

In 2012, torque gauge indication fluctuation was the most common fault and accounted for 41% of all faults that year. In 2016, clutch and engine filing accounted for 45%, 28% and 17% respectively. The aforementioned group of specified faults occurred least frequently in 2020, followed by 2019 and 2017. It can be concluded that the right lessons have been learned in the last years of helicopter operation and maintenance, and that repairs have largely eliminated the most frequent faults. In 2018, the helicopter spent the fewest hours in the air, which may distort the statistics of faults occurring this year.

Another issue is reliability and failure rate. The results of the analysis show that reliability was at its highest level in 2018. In 2017, reliability was marginally lower with a significantly higher flight hours compared to the 2018 flight hours.

 DOI: 110.55676/asi.v4i2.88

BIBLIOGRAPHY

Al-Fatlawi A., Jármai K., Kovács G., Optimization of a Totally Fiber-Reinforced Plastic Composite Sandwich Construction of Helicopter Floor for Weight Saving, Fuel Saving and Higher Safety. Polymers, 2021. https://doi.org/10.3390/polym13162735.

Nascimento C., Felipe A., Majumdar A., Ochieng W.Y., Helicopter Accident Analysis. Journal of Navigation, 2013. https://doi.org/10.1017/s037346331300057x.

Capobianco G., Lee M.D., The Role of Weather in General Aviation Accidents: An Analysis of Causes, Contributing Factors and ISSUES. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2001. https://doi.org/10.1177/154193120104500241.

Commine Q., Outsourcing Aircraft Maintenance: What Impact on Flight Safety?. International Journal of Applied Research in Business and Management, 2023. https://doi.org/10.51137/ijarbm.2023.4.2.5.

Fultz A.J., Ashley W.S., Fatal Weather-Related General Aviation Accidents in the United States. Physical Geography, 2016. https://doi.org/10.1080/02723646.2016.1211854.

Gołda P., Manerowski J., Model Systemu Operacji Kołowania Samolotów. Logistyka 3 (2014): 7240–46.

Karatas M., Razi N., Gunal M.M., An ILP and Simulation Model to Optimize Search and Rescue Helicopter Operations. Journal of the Operational Research Society, 2017. https://doi.org/10.1057/s41274-016-0154-7.

Kok J.L. de, Leistikow I., Bal R., Patient and Family Engagement in Incident Investigations: Exploring Hospital Manager and Incident Investigators' Experiences and Challenges. Journal of Health Services Research & Policy, 2018. https://doi.org/10.1177/1355819618788586.

McMahon T.W., Newman D.G., Development of a Field-Deployable Psychomotor Vigilance Test to Monitor Helicopter Pilot Performance. Aerospace Medicine and Human Performance, 2016. https://doi.org/10.3357/amhp.4425.2016.

Morowsky K.A., Funk K., Understanding Differences in Helicopter Mission Sets Prior to Human Error Analysis. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2016. https://doi.org/10.1177/1541931213601330.

Pham H., Puckett Y., Dissanaike S., Faster On-Scene Times Associated With Decreased Mortality in Helicopter Emergency Medical Services (HEMS) Transported Trauma Patients. Trauma Surgery & Acute Care Open, 2017. https://doi.org/10.1136/tsaco-2017-000122.

Shappell S.A., Wiegmann D.A., The Human Factors Analysis and Classification System (HFACS), 2017. https://doi.org/10.4324/9781315263878-3.

Ss, M., Sarkar R., Ghosh D., Assessment of Fatigue Among Aviation Personnel Involved in Military Flying in India Employing Multidimensional Fatigue Symptom Inventory

– Short Form (MFSI-SF). Indian Journal of Aerospace Medicine, 2020. https://doi.org/10.25259/ijasm_14_2020.

Voogt, A. de, Uitdewilligen S., Eremenko N., Safety in High-Risk Helicopter Operations: The Role of Additional Crew in Accident Prevention. Safety Science, 2009. https://doi.org/10.1016/j.ssci.2008.09.009.

Zieja M., Smoliński H., Gołda P., Information Systems as a Tool for Supporting the Management of Aircraft Flight Safety. Archives of Transport 36 (2015).

Ziółkowski J., Małachowski J., Oszczypała M., Szkutnik-Rogoż J., Konwerski J. Simulation model for analysis and evaluation of selected measures of the helicopter's readiness, Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace EngineeringThis link is disabled, 2022, 236(13), pp. 2751–2762.

Zurek J., Zieja M., Ziolkowski J., Reliability of Supplies in a Manufacturing Enterprise. In Safety and Reliability - Safe Societies in a Changing World, edited by S. Haugen, A. Barros, C. VanGulijk, T. Kongsvik, and J. E. Vinnem, 3143–47. Leiden: Crc Press-Balkema, 2018. https://www.webofscience.com/wos/woscc/full-record/WOS:000549917603087.

 DOI: 110.55676/asi.v4i2.88