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Artificial Intelligence Application on Aircraft Maintenance: A Systematic Literature Review

Erna Shevilia Agustian [1,*], Zastra Alfarezi Pratama [2]

[1] Aeronautical Engineering, The Air Marshal Suryadarma Aerospace University, Indonesia
[2] Informatic Engineering, Insan Cita Indonesia University, Indonesia

Abstract

Maintenance is an essential aspect of supporting aircraft operations. However, there are still several obstacles and challenges in the process, such as incomplete technical record data, irregular maintenance schedules, unscheduled component replacement, unavailability of tools or components, recurring problems, and a long time for troubleshooting. Digitalization and the massive use of artificial intelligence (AI) in various sectors have been widely carried out in the industry 5.0 era today, especially in the aviation industry. It offers several advantages to optimize aircraft maintenance and operations, such as predictive maintenance, fault detection, failure diagnosis, and intelligent monitoring systems. The utilization of AI has the potential to solve obstacles and challenges in aircraft maintenance activities, such as improving aircraft reliability, reducing aircraft downtime, improving safety, and reducing maintenance costs. This research uses the Systematic Literature Review method, which aims to review and provide an understanding of objectives, strategies, methods, and equipment objects involved in the application of AI in aircraft maintenance and repair scope. The findings and understanding from this research can be used as a basis for utilizing or adopting AI in aircraft maintenance to be more targeted and efficient in the future. This study reviews and presents research trends from reputable journals and proceedings screened using a unique protocol.

Keywords: Artificial intelligence, Aircraft maintenance, Industry 5.0

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1. Introduction

Indonesia is the largest archipelago in the world. Therefore, the Indonesian people need aircraft transportation that connects between islands quickly. According to data from BPS (Indonesian Statistic Institution), in 2018, the number of airplane passengers in Indonesia was around 101 million for domestic flights in one year [1]. Aircraft can be the safest mode of transportation compared to other transportation, but if a plane has an accident, the impact is very high, and the flow of news information worldwide is also high. In the last two decades, Indonesia has had 45 fatal airplane crashes. A total of 30 fatal accidents occurred during 2002-2011, while another 15 fatal accidents in 2012-2021 [2]. Outside these records, there are still technical problems such as aircraft derailments, engine problems, wing damage, etc. One of the causes is related to maintenance. The factor causing aircraft accidents related to maintenance includes maintenance activities that do not solve problems and repeated errors that are not resolved.

There is the use of tools that are not by procedures and misinterpretation of inspection intervals [3]. Whereas with the need to use aircraft as a means of transportation for the

*Corresponding author. Email: ernashevilia@unsurya.ac.id

community, the aircraft must be considered in its condition and state so that it is always in a flightworthy state and the best performance, so it requires good maintenance as well. Aircraft maintenance is defined by ICAO (International Civil Aviation Organization) as tasks that need to be performed on aircraft to ensure their continued airworthiness. Aircraft maintenance involves several activities, such as repairing, inspecting, overhauling, troubleshooting, and modifying various aircraft components, sub-systems, or systems [4]. These actions are to keep the equipment in it so that it is always in a serviceable condition and can be used properly according to its function.

The era of Industry 4.0 and Society 5.0 has transformed various fields, including the aviation industry. Various technologies have emerged, such as artificial intelligence, the Internet of Things, big data, virtual reality, augmented reality, and so on. With the emergence of these technologies, there are also new maintenance concepts such as Predictive maintenance, Prescriptive maintenance, maintenance 4.0, and others. These concepts provide added value, such as increasing availability, reducing downtime, increasing safety, and reducing costs. The existence of the maintenance 4.0 concept is inseparable from artificial intelligence. That is because artificial intelligence is used as decision support. Artificial intelligence is a field of science that has many branches. Machine learning, deep learning, expert systems, computer vision, and NLP are branches of artificial intelligence. In addition, there are still divisions within these types of artificial intelligence.

The problems that still arise in the aircraft maintenance area, it is hoped that artificial intelligence can support decisions, planning, and analysis related to maintenance problems, as in the new concept of maintenance 4.0, which offers several benefits and conveniences. This research is expected to be an initial reference for researchers who want to approach artificial intelligence technology in the aircraft maintenance area.

2. Methodology

2.1. Systematic Literature Review

The methodology used in this research is a Systematic Literature Review (SLR). SLR has been widely used in various fields of research, which was originally used in the health sector. Researchers usually use SLR to assist in compiling and analyzing information to support future research plans. SLR is a methodology used to collect, identify, and critically analyze relevant previous studies [5].

SLR produces answers and findings compiled from various studies so that conducting SLR can provide the findings needed in future research. This is because starting research requires an initial idea, namely by conducting a literature review. SLR can help with the initial search for relevant literature. A relevant literature review can help determine whether the topic is too broad to cover in a given timeframe adequately and whether the focus needs to be narrowed [6]. It can even help researchers find new findings or points in previous research plans. To achieve this, conducting a systematic literature review must follow the seven key principles of the literature review [7], that is: (1) Transparency, (2) Clarity, (3) Integration, (4) Focus, (5) Equality, (6) Accessibility dan (7) Coverage.

In conducting a systematic literature review, three main stages must be carried out: planning, conducting, and reporting [8].

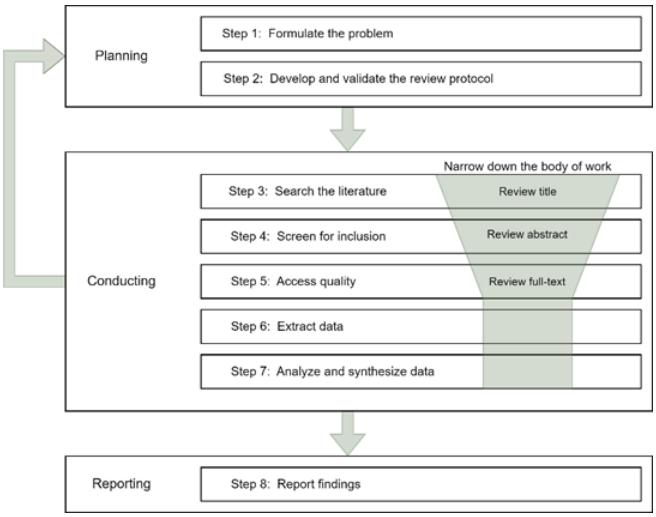

Figure 1. Process of systematic literature review [8].

At the planning stage, the researcher identifies the need to conduct a review, then determines the research question and creates a protocol for the search. At this stage, the researcher briefly searched similar studies to ascertain whether other researchers had answered the research questions. A research protocol is needed to make the search process effective and on target so that the search process is focused and does not widen. Furthermore, in the conducting process, the search process is carried out in several reputable databases or journals relevant to artificial intelligence and aviation, such as IEEE, Science Direct, MDPI, Hindawi, and SpringerLink. Furthermore, the researchers conducted screening by reviewing the abstract title, as well as several predetermined criteria. After obtaining several main articles from the screening results, extraction, analysis, and synthesis were carried out by exploring article by article to find the points needed to answer research questions. The last process is to make a report in the form of an article with a format following the publication publisher's standards. In the review process, according to Fig.2, it is allowed to do the iteration process. This is done if several problems arise that ultimately require modification to maximize results. For example, problems that require iteration, such as problems that are still too broad, errors in the preparation of inappropriate keywords, or criteria that complicate the process of finding the required articles.

2.2. Research Question

The research question is the purpose of this research, so the research question is determined at the beginning of the research. Research questions are defined to make the research direction more focused so that the essence of conducting a literature review will be more precise and efficient in answering research
gaps. The research question and its search motivation can be seen in Table 1.

Table 1. Research Question (RQ).

ID	Research Question	Motivation
RQ1	What parts or components use artificial intelligence the most in aircraft maintenance research?	To find out the system, object, or aircraft component that most used artificial intelligence in the aircraft maintenance process.
RQ2	What are the goals and objectives of using artificial intelligence in aircraft maintenance research?	To determine the purpose and end goal of using artificial intelligence in aircraft maintenance.
RQ3	What data sources are used in artificial intelligence research in the aircraft maintenance area?	To find out where the data sources used by artificial intelligence in the aircraft maintenance area come from.
RQ4	What are the most widely used methods when implementing AI in aircraft maintenance?	To identify the most used methods in the use of artificial intelligence in the aircraft maintenance area.

2.3 Result Finding

To collect the various articles needed, a search strategy is needed. The process of collecting research articles is intended to be precise and efficient. Some important things to do in this process are determining the journal database, creating keywords and keyword alternatives, and determining criteria. After identifying the fields related to aircraft maintenance, several reputable journal databases were determined, such as:

1. IEEE Xplore (Institute of Electrical and Electronics Engineers), Access: https://ieeexplore.ieee.org/
2. MDPI (Multidisciplinary Digital Publishing Institute), Access: https://www.mdpi.com/
3. Hindawi, Access: https://www.hindawi.com/
4. Science Direct, Access: https://www.sciencedirect.com/
5. ACM (Association for Computing Machinery), Access: https://dl.acm.org/
6. SpringerLink, Access: https://link.springer.com/
7. IOP Science, Access: https://iopscience.iop.org/

Artificial intelligence is a field of study with a broad scope. Artificial intelligence encompasses many theories, methods, and technologies, and there are sub-fields underneath. Therefore, alternative keywords were used to find more articles on artificial intelligence and its derivatives to make the research more comprehensive. This was also used for the alternative keyword for "aircraft," as shown in Table 2.

Table 2. Alternative Keyword

Keyword	Alternative Keyword
Artificial Intelligence (AI)	Machine learning, Deep learning, Expert Systems, Neural network
Aircraft	Aviation, Airplane

In formulating the search formula, the "AND" OR " keywords automatically facilitate the query or search process in the journal database. The string formulas used are:

(Aircraft OR Aviation OR Airplane) AND (Artificial Intelligence OR Machine Learning OR Deep Learning OR Expert System OR Neural Network) AND (Maintenance)

Other string formula combinations can be an alternative because some journal databases have different search or query capabilities. In addition, there is also a limit to the number of keywords that can be entered in the article search field. However, alternative string formulas must still use the main keywords and not go outside the scope of aircraft maintenance.

Next, a search is conducted using a string formula based on the keywords that have been compiled. This process is done by considering several aspects, including subject area (Engineering, Computer Science, Aviation), publication type (journal and conference), document type (.pdf), and year of publication (2015-2023). The mechanism in this process will be adjusted to the Advanced Search in each journal database. The search results using the string formula can be seen in Table 3.

Table 3. Result From Journal Database.

Database Journal	Articles Found
IEEE Xplore	275
MDPI	20
Hindawi	117
Science Direct	628
ACM	669
SpringerLink	500
IOP Science	156
Total	**2365**

Several articles were found, but screening was required to find articles relevant to the research questions and objectives. The title, abstract, publication date, type, and

article access were identified in this process. The screening of articles based on the criteria can be seen in Table 4.

Table 4. Specific Criteria.

Inclusion Criteria	Exclusion Criteria
– Article published before August 2023 – discussion related to aircraft components and maintenance scope – article-related keyword with string formula – subscription journal and full-access or open-access	– White paper, book, conference review, conference abstract, Encyclopedia, and magazine or newsletter – discussion out of the aviation industry area – similar articles but from different databased – not written in English

After filtering articles using specific criteria, several key articles were obtained that will be studied more deeply. These main articles will be used to answer the research question. Some articles used alternative combinations of string formulas, but others were found outside the database list mentioned earlier. However, the articles must be based on the criteria and included in the quartile (Q1-Q4). The final results of the number of article findings in this study can be seen in Table 5.

Table 5. Result of Specific Criteria

Category	Articles
Q1	8
Q2	9
Q3	3
Q4	-
Conference Proceeding	5
Total	**25**

3. Result and Discussion

3.1 RQ 1 - What parts or components use artificial intelligence the most in aircraft maintenance research?

Table 6. Object Research based on the part of aircraft

No	Part	Reference
1	Engine	[9],[10],[11],[12],[13],[14], [15],[16], [17],[18]
2	Turbofan Engine	[19],[20],[21],[22], [23]
3	Rivet aircraft	[24]
4	Aircraft in General	[25],[26]
5	Landing Gear	[27]
6	Cooling System	[28]
7	Wing	[29]
8	Aircraft Fuel System	[30]
9	Aircraft Fuselage	[31]
10	Aircraft control system	[32]
11	Auxiliary power unit	[33]

After a deeper study of 25 research articles, it was found that most research on the use of artificial intelligence was carried out on the engine part of the aircraft (10 articles). As for some turbofan components (5 Articles), it is a sub of the aircraft engine. The results can be seen in Table 6.

3.2 RQ 2 - What are the goals and objectives of using artificial intelligence in aircraft maintenance research?

The results show that the objectives of using artificial intelligence in the aircraft maintenance area are prediction, estimation, classification, detection, prediction, and combination. Prediction is the most common goal in artificial intelligence research on aircraft maintenance. Some studies want to achieve more than one goal, such as in [13], [24], [25]. The results of each goal also have several types of their own, for example, in predictions with several different types of goals such as for RUL (Remaining Useful Life), Performance, and failure. The results of the article review can be seen in Table 7.

Table 7. Objective of research AI in aircraft maintenance

Objective/goal				
Prediction/ Estimation	**Classification**	**Detection**	**Prognostic**	**Combination**
Remaining Useful Life Prediction: [19], [20],[11],[27],[28], [22],[23],[17],[33]	Failure Classification: [9]	Corrosion detection: [31]	Remaining Useful Life Prognostics: [21]	Identification and Prediction: [25]
Performance Prediction: [29] Estimation: [10], [14],[15],[16] Predict the evolution: [12] Prediction of replacement: [26] Failure rate prediction: [30]	Classification state: [18]	Fault detection: [32]		Classification and anomaly detection: [24] Predictive and Prognostic: [13]

There are 4 main objectives of using artificial intelligence for aircraft maintenance based on the findings in a number of papers, namely prediction/estimation, classification, detection and combination:

1. Prediction algorithms are computational procedures or steps used to predict future values or events based on available data. Prediction algorithms can be used in various fields, including statistics, machine learning, and data mining.

2. Classification algorithms are mathematical methods or procedures used to group or classify data into specific classes or categories. The main goal of a classification algorithm is to create a model that can predict the class or label of data based on information learned from previous training data.

3. Detection algorithms are used to identify the presence or characteristics of certain objects or patterns in data. The type of detection algorithm used will depend on the context and purpose of the detection.

4. Prognostic algorithms are used to predict future developments or events based on historical data and identified trends. Prognosis is an attempt to estimate how a condition or situation will develop over time.

5. While combination is a mixture of several objectives, for example, it can combine prediction and detection or identification and prediction such as research [25], classification and detection [24] and prediction and prognostic [13].

3.3 RQ 3 - What data sources are used in artificial intelligence research in the aircraft maintenance area?

An important aspect of using artificial intelligence is the availability and how to collect data. The findings in this research question review show that using the C-MAPSS public dataset from NASA (National Aeronautics and Space Administration) is the most widely used data source in artificial intelligence research in the aircraft maintenance area. There are 15 types of data sources found. This is because there are differences in the objectives and needs of using artificial intelligence in the aircraft maintenance area and the availability or capabilities of MRO systems in several research locations. The findings can be seen in Table 8.

Table 8. Data sources

No	Data Sources	Reference
1	C-MAPSS Dataset	[19],[20],[21],[11],[13], [22],[15 ,[16],[17]
2	ACARS (Aircraft Communications Addressing and Reporting System)	[25]
3	Google Smart Glass Video (Take video & picture)	[24]
4	Data Sensor	[29], [33],[18]
5	CFD (Computational Fluid Dynamics) Simulation Software	[29]
6	QAR (Quick Access Recorder) Data	[9], [32]
7	Health monitoring information	[10]
8	PHM08 Dataset	[11]
9	FDR (Flight Data Recorder)	[27]
10	Flight Phases Data	[28]
11	Run to Failure data/Historical failure data	[28],[30]
12	N-CMAPSS Databased	[12]
13	FD001 Dataset	[23]
14	DAIS (D-Sight Aircraft Inspection System)	[31]
15	ACMS (Aircraft Central Maintenance System)/Log Maintenance	[26]

3.4 RQ 4 - What are the most widely used methods when implementing AI in aircraft maintenance?

The review found that LSTM (Long Short-Term Memory) and CNN (Convolutional Neural Network) are the most widely used methods. LSTM is generally used for prediction, while CNN is used for classification and detection. LSTM and CNN can also be combined as in [14]. Some studies also use layered methods such as in [19], [25], [9], [21]. Some methods are also basically not included in the artificial intelligence sub but use statistical methods, but can be used to make predictions, such as in [27] and [30], which use the ARIMA (Autoregressive Integrated Moving Average) method. The results of the review can be seen in Table 9.

Table 9. Method

No	Method	Reference
1	SAE (Stacked Autoencoder)	[19]
2	TCN (Temporal Convolutional Network)	[19]
3	LSTM (Long Short-Term Memory)	[20],[25],[10],[14],[16], [33]
4	Bi-LSTM (Bidirectional Long Short-Term Memory)	[9]
5	PSO-SVM (Particle Swarm Optimization-Support Vector Machine)	[25]
6	CNN (Convolutional Neural Network)	[24],[9],[21],[13],[14],[31]
7	ANN (Artificial Neural Network)	[29]
8	DRL (Deep Reinforcement learning)	[21]
9	DL-RNN (Deep Layer Recurrent Neural Networks)	[11]
10	ARIMA (Autoregressive Integrated Moving Average)	[27], [30]
11	GAM (generalized additive model)	[12]
12	GA (Genetic Algorithm)	[22]
13	ELM (Extreme Learning Machine)	[23]
14	DCNN (Deep Convolution Neural Network)	[15]
15	NSA (Negative selection Algorithm)	[32]
16	DNN (Deep neural networks)	[18]
17	OS-ELM (Online Sequential Extreme Learning Machine)	[17]

These methods are algorithms used in aircraft maintenance research. It can be seen that research on aircraft maintenance involving artificial intelligence can use various and different algorithms. This depends on the object of research, data and objectives. For example, the research objectives are for detection, diagnosis, prediction and classification will use different algorithms.

3. Conclusion

The conclusion of this article has 4 points which are the results of the findings and answers to the research questions.

1. The utilization of artificial intelligence in the aircraft maintenance area is most widely used for aircraft engines. Artificial intelligence is most widely used to predict several things, such as Remaining Useful Life Prediction, Failure prediction, performance prediction, etc.
2. Most researchers utilize the C-MAPSS public dataset because the dataset has several parameters that are much needed and easily accessible for research purposes. In addition, it should also be remembered that aircraft have a very complex system, so conducting research in aircraft maintenance must be careful and prepared if the research results are used in real decisions in the aircraft maintenance process.
3. Several support systems are needed for the application of artificial intelligence in aircraft maintenance, such as Health monitoring systems, Aircraft inspection systems, sensor systems, and reporting systems. The basic ones needed are historical failure logs and historical maintenance logs.
4. LSTM (Long Short Term Memory Network), a technique that is widely used for prediction, can process, predict, and classify information based on time series data. The idea behind LSTM allows it to remember and delete old data that is no longer relevant. Thus, information management will be more complete as well as up-to-date.

For further research is to be able to determine the object of research in advance such as engines, wings, turbo fans, and so on. This is needed to minimize the scope of future research. It is also necessary to consider the source of data to be used whether the aircraft system has a data storage log or not, if not then it can use the available open data, but it is ideal to use your own data to match the character of the aircraft industry environment to be studied.

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