APU STARTER MOTOR RELIABILITY ANALYSIS P/N 2704506 – 4 AIRBUS A320S USING WEIBULL DISTRIBUTION AND FAILURE MODE AND EFFECT ANALYSIS AT PT INDONESIA AIRASIA

Yogi Prisma[1], Caesar Pradewa[2], Feti Fatonah[3] , Djoko Herwanto[4], Desiana Putri[5], Muchammad Furqon[6], Suroso[7], Dikasitama[8]

[1]Indonesian Aviation Polytechnic; [2]Indonesian Aviation Polytechnic; [3]Indonesian Aviation Polytechnic;
[4]Pamulang University; [5]National Air And Space Power Center Of Indonesia
[1,2]yogiprisma9@gmail.com@gmail.com; [3]fetifatonah@yahoo.com; [4]Djoko.herwanto58@gmail.com;
[5]desianaputri2112@gmail.com; [6]muchammadfurqon10@gmail.com
[7,8]ikeo.santai@gmail.com;

Abstrak — *This study aims to determine the reliability value and failure characteristics of the APU starter motor P/N 2704506-4, as well as to identify the failure mode qualitatively to provide improvement recommendations for PT Indonesia AirAsia. The starter motor in the auxiliary power unit (APU) is a vital component that functions to start the operating cycle. The method used is a mixed method, with quantitative analysis through processing historical time to failure data from 20 unscheduled removal cases using the Weibull distribution, and qualitative analysis through failure mode and effect analysis. Data were obtained from the Aircraft Maintenance Manual, Component Maintenance Manual, and semi-structured interviews with engineers. The analysis results show a value of β = 2.029 (β>1) which indicates a wear-out failure pattern. The scale parameter η recorded 3,095.71 flight hours with a mean time to failure of 2,742.85 hours. Reliability projections show that at 2,800 hours, reliability drops to 44.23% with a failure probability of 55.77%. The FMEA analysis identified three failure modes: brush wear, terminal winding burn, and oil contamination. Of these, brush wear was the dominant failure mode, with 12 cases and the highest RPN value (252). The study concluded that starter motor failure is predictive and dominated by brush wear. The primary recommendation is to transition to a preventive maintenance strategy through visual inspection of brush wear indicators and scheduled replacement at 2,500–2,600 flight hours to reduce unscheduled removals and increase aircraft availability.*

Keywords: *APU starter motor, Weibull analysis, FMEA, Reliability, Unscheduled Removal, Airbus 320.*

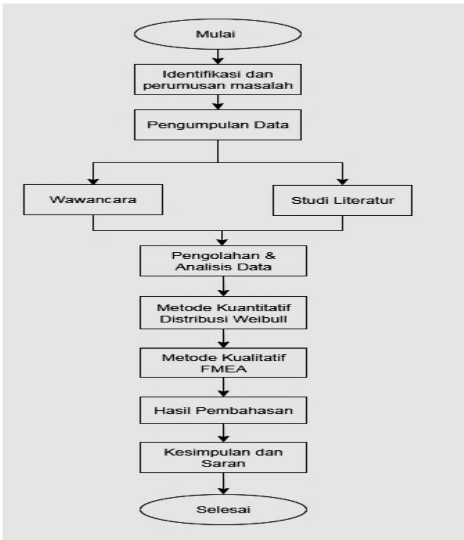
1. INTRODUCTION

The air transportation industry is currently experiencing rapid growth, marked by increasing passenger volumes, cargo volumes, and aircraft movements (Ahmad et al., 2023). Along with this growth, every airline bears the crucial responsibility of carrying out routine maintenance on its aircraft fleet, engines, propellers, and other components (Law No. 1 of 2009, 2009). This maintenance aims to ensure that each fleet meets airworthiness standards, which are the primary foundation for ensuring flight safety and security (Huda, 2024). One vital system in modern aircraft operations is the auxiliary power unit (APU), a smaller gas turbine engine typically located in the tail section of the aircraft. The APU's primary function is to independently provide electrical power and compressed air (pneumatics) when the main engine is not operating, particularly when the aircraft is on the ground (Firdaus et al., 2024). The causes of APU Auto shutdown include damage to the APU starter motor component due to excessive operation (Fadhil & Bakar, 2020). The starter motor is *a vital component for the APU, which functions to convert electrical energy into mechanical energy used to drive the compressor at the start of the starting process. Without its function, the APU cannot be started. The starter motor is a vital component for the APU, which functions to convert electrical energy into mechanical energy used to drive the compressor at the start of the starting process. Without its function, the APU cannot be started. A number of previous studies have applied reliability analysis to different components. For example, research by (Rahmawati & Mulyani, 2020) used the Weibull distribution to analyze failures in nose wheel assy, the main advantage of Weibull analysis is its ability to provide fairly accurate failure analysis and failure predictions with very small samples (Abernethy, 2008). Meanwhile (Faizal & Arifin, 2017) applied failure mode and effect analysis (FMEA) to the electrical system. However, no research has been found that specifically combines quantitative analysis through Weibull distribution with qualitative analysis using FMEA to evaluate the reliability and identify the dominant failure mode in the APU starter motor P/N 2704506-4 in the operational environment of PT Indonesia AirAsia.*

2. RESEARCH METHODS

This research systematically uses two analytical techniques called mixed methods. Mixed methods is an approach to inquiry that involves collecting quantitative and qualitative data, integrating both forms of data, and employing different designs that may involve philosophical assumptions and theoretical frameworks. The main assumption of this form of inquiry is that the integration of quantitative and qualitative data yields additional insights beyond the information provided by either quantitative or qualitative data. Quantitative research is the process of acquiring knowledge based on numerical data (Purwanza et al., 2025). Qualitative research is research that uses observation to study something in its natural state, understand or interpret something, and make sense of phenomena by describing, decoding, translating, and understanding the context in which it occurs (Waruwu, 2024). This research primarily employs quantitative methods, namely Weibull analysis, and qualitative research using FMEA as supporting data for the quantitative method. This study aims to determine the reliability value of components as well as the factors and impacts of damage to the APU starter motor component P/N 2704506 – 4 on 30 Airbus 320 aircraft at PT Indonesia AirAsia. There were 20 unscheduled removals of the APU starter motor component P/N 2704506 – 4 over a period of 7 years (2018 – 2024).

2.1. *Research Flowchart*



Motor Starter Research Flowchart
Source: Author's Processed Results

The flowchart illustrates a systematic research methodology, which begins with the identification stage and a clear formulation of the problem. Once the problem is determined, the process continues with the collection of relevant data through two approaches: interviews to obtain primary data and literature studies for secondary data. The collected data is *then processed and analyzed in stages, starting with quantitative analysis using the Weibull Distribution to assess reliability or failure data, which is then continued with qualitative analysis using the FMEA method to identify failure modes and their impacts. The results of both analyses are then discussed in depth for interpretation, which ultimately becomes the basis for drawing conclusions and providing recommendations as a closing stage before the research process is considered complete.*

2.2. Time and Location of the Research

The research was conducted at PT. Indonesia AirAsia, located at Red House, Jalan Marsekal Suryadarma No.1, Sela pajang Jaya Subdistrict, Neglasari District, Tangerang City, Banten 15127, Indonesia. The research was conducted over a five-month period, from November 2024 to March 2025.

2.3. Research Data Collection

This research used two data sources: primary data and secondary data. Primary data is data collected directly from original sources. It is typically used to generate accurate information in accordance with factual conditions, so that the resulting information can assist decision-making (Pramiyati, 2017). Secondary data, data previously collected by researchers or organizations, is referred to as secondary data sources (Hafizah et al., 2025). All collected documents served as the primary data sources for this study and included a variety of relevant references to support the analysis process:

- *Information on APU starter motor components P/N 2704506 – 4, AMM, CMM, TSM.*
- *Operator-owned aircraft maintenance log documents. The researcher used this data as the primary data to determine its reliability based on the applied method.*
- *The researcher conducted interviews to obtain the necessary data. These interviews were conducted with informants who were engineers at PT Indonesia AirAsia, specifically aircraft maintenance engineers (AMEs) with a type rating of Airbus 320. The author used triangulation in the interviews. Triangulation in qualitative research is a strategic approach to increase the credibility, validity, and depth of research findings through the use of multiple sources or methods (Nurfajriani et al., 2024).*

3. RESEARCH RESULTS AND DISCUSSION

In the research and discussion of the APU starter motor reliability analysis, specifically on the Airbus 320 aircraft, the researcher can conclude, among other things:

- *Determine the reliability value of the APU starter motor component P/N using reliability analysis on the Airbus 320 aircraft at PT Indonesia AirAsia.*
- *What is the cause of the failure of the APU starter motor component P/N 2704506-4 on the Airbus 320 aircraft at PT Indonesia AirAsia?*

3.1. Design Stages

The required data is collected, the next step is data processing and analysis. To achieve these objectives, the collected data will be processed and analyzed according to established procedures:

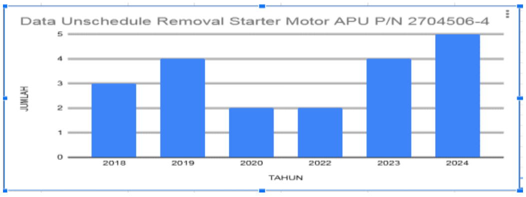
- *Quantitative Approach with Weibull Distribution*
- *Determining the Time to Failure (TTF) value. The TTF value can be determi ned from maintenance data on the APU starter motor component from 2018 to 2024. The data entered is the time between installations (TBI).*
- *Creating a data table for unscheduled removals of the APU starter motor P/N 2704506-4 from 2018-2024.*
- *Creating a linear regression equation table and its calculations.*

- *Calculating the reliability, unreliability, and failure rate of the APU starter motor component P/N27045064.*
- *Qualitative Approach with the Failure Mode and Effect Analysis Method*
- *Observing or analyzing components*
- *Creating a list of potential failures and their effects*
- *Determining the severity (S) value*
- *Determining the occurrence value (O)*
    - *Determine the detection value (D)*
    - *Calculate the risk priority number for each failure method RPN = S x O x D*
    - *Determine the priority*

3.2. *Research Results*

The results of the research conducted can be presented as follows:

3.2.1. *Calculating the Quantitative Approach with the Weibull Distribution*



PU Starter Motor Replacement Chart
Source: Aircraft Maintenance Logbook

The image above is a graph of the replacement of the APU starter motor component P/N 2704506–4. Unscheduled removal or unscheduled removal in the period from 2018 to 2024 on 30 Airbus 320 aircraft, with a total of 20 incidents and the largest number occurring in 2024 with 5 incidents. To calculate the reliability, unreliability, mean time to failure (MTTF) and failure rate of the APU starter motor component P/N Airbus 320 operated at PT Indonesia AirAsia, this data will be included in the calculation. The data obtained is processed to determine the Weibull distribution parameters which are the basis for calculating the reliability, Mean Time To Failure (MTTF), and failure rate of the APU Starter Motor component of Airbus A320 aircraft at PT Indonesia AirAsia.

3.2.2. *Linear Regression*

After analyzing the damage data based on flight hours for the starter motor component, a linear regression equation was entered to determine the shape and scale parameters by finding the values of a and b.

ΣLn(-(Ln(1-MR)))	Σxiyi	ΣLn(TTF)	ΣXi2
-10,88906966	-71,74674672	155,38995	32,018393

Linear Regression Source: Author's Processed Results

3.2.2. *Determining the Parameters β and η*

From the results of the linear regression calculation in the table, the values of β and η were then found using linear regression with the equation. The following values were obtained:

$$B = \frac{\sum_{i=1}^{n} X_i Y_i - \frac{\sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{n}}{\sum_{i=1}^{n} X_i^2 - \frac{\left(\sum_{i=1}^{n} xi\right)^2}{n}}$$

$$B = \frac{-71{,}74674672 - \frac{(-10{,}88906966) + (155{,}3899567)}{20}}{32{,}01839306 - \frac{-10{,}88906966^2}{20}}$$

$B = 0{,}4927540997$

$A = \bar{Y} - B\bar{X}$

$A = 7{,}769\bar{4}97836 - (0{,}4927540997)x(-0{,}54\bar{4}4534832)$

$A = 8{,}037779522$

Then determine the parameter values (β) and (η) using the equation

$\eta = e^a$

$\eta = 2.71828182^{8{,}037779522}$

$\eta = 3095{,}714813$

Note: e is a constant with a value of 2.71828182.

The calculated Weibull distribution parameters are presented in the table.

Parameter	Nilai
Shape (β)	2,029409802
Scale (η)	3095,714813

Eta and beta parameters Source: Author's Processed Results

3.2.3. *Reliability Calculation*

Reliability calculations use the equation with (t) according to the number of
flight hours

R(t)= $e^{-\left(\frac{t}{\eta}\right)^{\beta}}$

Reliability umur t= 0 FH

R(t)= $2{,}718281828\left(-\frac{0}{3095{,}714813}\right)^{2{,}029409802}$

R(t)= 1
R(t)= 100%

Reliability umur t= 2742,84798 FH

R(t)= $2{,}718281828\left(-\frac{2742{,}84798}{3095{,}714813}\right)^{2{,}029409802}$

R(t)= 0,4573837834
R(t)= 45,74%

Reliability umur t= 2800 FH

R(t)= $2{,}718281828\left(-\frac{2800}{3095{,}714813}\right)^{2{,}029409802}$

R(t)= 0,4423450769
R(t)= 44,23%

3.2.4. *Mean Time to Failure Calculation*

Mean time to failure (MTTF) analysis, which literally means calculating the average time until a failure occurs, is a particularly useful and relevant method for determining the estimated operational life of a component, device, or system. MTTF calculations are performed using the following formula:

$$\mathrm{MTTF} = \eta\Gamma\left(\frac{1}{\beta}+1\right)$$

$$\mathrm{MTTF} = 3095{,}714813\,\Gamma\left(1+\frac{1}{2{,}029409802}\right)$$

MTTF = 27742,84798 FH

3.2.5. *Unreliability Calculation*

Unreliability values are determined by applying a formula, resulting in the following results:

F(t)=1- $e^{-\left(\frac{t}{\eta}\right)^{\beta}}$

Unreliability umur t = 0 FH

F(t)= $1-2.71828182845904\Gamma\left(-\frac{0}{3095{,}714813}\right)^{2{,}029409802}$

F(t)= 0
F(t)= 0%

Unreliability umur t = 1600 FH

F(t)= $1-2.71828182845904\Gamma\left(-\frac{1600}{3095{,}714813}\right)^{2{,}029409802}$

F(t)= 0,2304828158
F(t)= 23,05%

Unreliability umur t = 2742,84798 FH

F(t)= $1-2.71828182845904\Gamma\left(-\frac{1600}{3095{,}714813}\right)^{2{,}029409802}$

F(t)= 0,5426162166
F(t)= 54,26%

3.2.6. *Failure Rate Calculation*

The failure rate, also commonly known as the failure rate, measures the frequency of failures in a component or system. Simply put, this metric can be understood as the number of failures that occur per unit of time. In other words, it is the probability that an item, which has survived and functioned normally up to a certain point, will fail at a later point. To determine the failure rate, the formula equation is used, where time (t) is the value of flight hours *Failure rate for age t = 0 FH*

λ (t)= $\left(\frac{2{,}029409802}{3095{,}714813}\right)\left(\frac{0}{3095{,}714813}\right)^{2{,}029409802-1}$

λ (t)= 0

Failure rate untuk umur t = 1600 FH

λ (t)= $\left(\frac{2{,}029409802}{3095{,}714813}\right)\left(\frac{1600}{3095{,}714813}\right)^{2{,}029409802-1}$

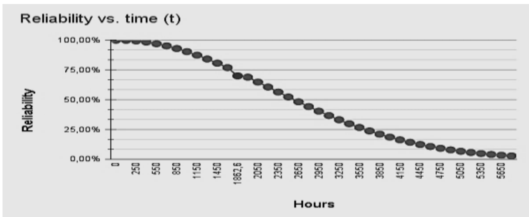
λ (t)= 0,0003323057009

Failure rate untuk umur t = 2742,8479 FH

λ (t)= $\left(\frac{2{,}029409802}{3095{,}714813}\right)\left(\frac{2742{,}84798}{3095{,}714813}\right)^{2{,}029409802-1}$

λ (t)= 0,0005787671126

3. 3.2.7. *Motor Starter Reliability Graph*



APU Starter Motor Reliability Graph
Source: Research Results

The graph shows the correlation between reliability and flight hours. It can be seen that the reliability of the APU starter motor component P/N 2704506 – 4 decreases with flight hours. In other words, the longer the component is in operation.

3.2.8. *Reliability Based on Indonesian Industry Standards*

Based on the reliability calculations for the APU starter motor P/N 2704506-4 on an Airbus 320 aircraft operated by PT Indonesia AirAsia, the reliability value is 44.23% at 2,800 flight hours. Based on the

Indonesian industry standard, this value is below the 70% reliability limit. The 70% reliability level is achieved at 1,862.6 flight hours. The calculation is as follows: Reliability at 1,862.6 flight hours

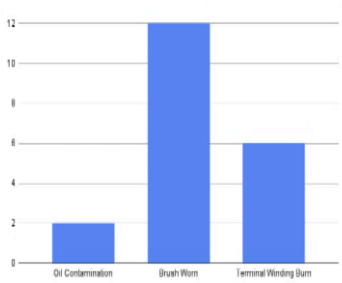
$$R(t)= 2{,}718281828\left(-\frac{1862{,}6}{3095{,}714813}\right)^{2{,}029409802}$$

R(t)= 0,7000254745

R(t)= 70 %

3.2.9. *Qualitative Analysis Approach with FMEA*

The author conducted a qualitative analysis using Failure Mode and Effect Analysis (FMEA) to determine, discover, prioritize, and eliminate known failure effects or potential failures of a system or component. The goal is to eliminate failure modes and reduce risk.



Graph of Unschedule Removal Failure Types
Source: Research Results

The number of unscheduled removal events on the APU Starter motor component P/N 2704506-4 in 30 Airbus 320 aircraft of PT Indonesia AirAsia, that the causes of unscheduled removal of the APU Starter motor component are oil contamination, brush worn, and terminal winding burn, and brush damage is the biggest cause with a total of 12 of the 20 unscheduled removal events that occurred from 2018 to 2024. This data was collected by the author based on the grouping of the number of damages seen from the shop report on the APU starter motor component P/N 2705506-4. From the type of unscheduled removal events that the author conducted interviews as supporting data to create FMEA worksheets and RPN worksheets.

3.2.10. FMEA *Worksheet*

To identify the source of damage to the APU starter motor component, the author uses the FMEA worksheet as the FMEA processing method. The purpose of the potential failure mode is to show various types of starter motor failures that have occurred during the operation of the Airbus 320 aircraft at PT Indonesia AirAsia. The purpose of the potential cause of failure is to find the main source of the failure. In addition, the potential effect of failure explains how a component is affected and what consequences occur when the system performs its function, and detection control explains how to identify failures so that a failure can be detected.

Component	Potential Failure Mode	Potential effect of failure	Potential cause of failure	Current Control Preventin
Starter motor APU	*Brush Worn*	Dampak paling langsung adalah penurunan kinerja motor, yang menyebabkan daya yang lebih rendah atau bahkan kegagalan total untuk menghidupkan APU (*fail to start*).	Penyebab utama adalah gesekan normal dan berlebihan antara *brush* dan *commutator* selama motor beroperasi, Tekanan pegas (*spring*) yang tidak optimal baik terlalu rendah maupun terlalu tinggi dapat menyebabkan loncatan bunga api (*arcing*) dan gesekan berlebih yang mempercepat keausan.	Tindakan utama adalah penggantian unit *brush assemblies*. Jika *commutator* rusak, perlu dilakukan perbaikan *armature commutator* dengan mesin (*machining*) atau penggantian *armature assembly* dan melakukan inspeksi *brush wear indicator.*
	Terminal Winding burn	Dampak paling serius adalah kegagalan total *starter motor*. Panas ekstrem dapat melelehkan komponen di sekitarnya dan berisiko menimbulkan asap atau api, yang merupakan ancaman serius bagi keselamatan penerbangan	Penyebab utama adalah kerusakan pada isolasi kumparan (*windings*) akibat panas berlebih, getaran, atau kontaminasi (kelembaban, oli, debu)	Tindakan yang paling umum adalah penggantian total *field assembly* atau *terminal assembly* yang terbakar, karena integritas isolasi tidak dapat dipulihkan. Dalam kasus yang parah, seluruh motor mungkin perlu diganti.
	Oil Contaminti on	Oli dapat merusak *brush assemblies* (membuatnya lunak atau macet), merusak isolasi pada kumparan (*windings*) yang berujung pada *short circuit*, dan mempercepat degradasi pelumas pada *bearing*	Penyebab paling umum adalah kegagalan pada *sealing system*, terutama *seal* dan *packing* pada *front end bell assembly*. *Seal* dapat aus, retak, mengeras akibat suhu tinggi, atau rusak karena getaran.	Langkah paling penting adalah mengidentifikasi dan mengganti *seal* atau *packing* yang bocor atau rusak

FMEA Worksheet for Starter Motor
Source: Research Results

3.2.9. RPN *Worksheet*

After identifying and listing the various types of failures and effects caused by APU starter motor failure, the authors then *determined the risk priority number (RPN) for severity (S), occurrence (O), and detection (D) using an FMEA worksheet. Using the Airbus 320 maintenance manual, CMM, and interview results, these calculations and figures were generated based on team discussions.*

Component	*Potential Failure Mode*	*S*	*O*	*D*	*RPN*
Starter motor APU	*Brush Worn*	7	6	6	252
	Terminal Assy Burn	6	3	6	108
	Oil contamination	5	1	7	35

RPN Starter Motor Worksheet
Source: Research Results

From the table above, it can be concluded that the failure mode with the highest RPN value is Brush Worn on the APU Starter motor with an RPN value of 252. Therefore, to reduce the level of damage and increase the reliability value of the APU starter motor, a wear check of the starter motor brush can be carried out according to the AMM.

3.3. *Interpretation of Quantitative Analysis*

The quantitative analysis in this study used *the Weibull distribution method. The calculations yielded several results:*

- *The analysis showed a shape parameter (β) value of 2.029. Because this value is greater than 1 (β > 1), this indicates that the primary failure mode of the APU starter motor component P/N 2704506–4 is wear-out failure. This means that failure tends to occur with component aging and is predictable, rather than random.*
- *The mean time to failure (MTTF) of the APU starter motor component P/N 2704506–4 is 2,742.85 flight hours. This figure serves as a reference for estimating the component's lifespan before failure is likely.*
- *The reliability value of the APU starter motor component P/N 2704506–4 at 2,742.85 flight hours is 45.74%, indicating a low reliability index.*
- *The unreliability value for the APU starter motor component P/N 2704506–4 at 2,742.85 flight hours was 54.26%, indicating a high and significant risk of failure.*
- *Referring to the Indonesian industry reliability standard of 70%, an inspection of the APU starter motor P/N 2704506–4 can be scheduled for an operational age of 1,862.6 flight hours, with a component reliability level of 70%.*
- *There are two main indicators for determining component quality: beta (β) and MTTF. The beta value obtained by the author is 2.029, indicating that the component's failure characteristic is wearout, which is damage due to wear and tear due to frequent use. The calculated MTTF is 2,742.85 flight hours. This figure serves as the primary reference for a component reaching the end of its reliable service life. In other words, the starter motor can still be considered good long before it reaches the MTTF value, if it approaches or exceeds that number then the component is at risk.*

3.4. *Interpretasi Analisis Kualitatif*

In this study, a qualitative analysis was conducted using the failure mode and effect analysis (FMEA) method. The purpose of this analysis is to identify the types of failures that may occur, their causes, and their impacts, and to determine which failures should be prioritized in their handling. The results of the FMEA analysis indicate that:

- *Primary Failure Mode: Brushworn, or worn carbon brushes in the APU starter motor, has the highest risk.*
- *Risk Rating (RPN): Brushworn has the highest RPN, at 252, and is based on three factors: severity, occurrence, and detection.*
- *Cause of Failure: 12 of the 20 unscheduled component removals were*

caused by brushworn, according to data and interviews. Other identified causes were Terminal Assy Burn and oil contamination.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

- *Based on a reliability analysis using a two-parameter Weibull distribution, the APU starter motor component on an Airbus 320 aircraft operated by PT Indonesia AirAsia during the 2018-2024 period showed that, at an operational age of 2,742.85 flight hours, the reliability value was only 45.74%, while the probability of failure reached 44.26%. The characteristic life (α) value of 3,095.71 flight hours and the shape parameter (β) of 2.029 indicate that the component is in the wear-out phase, where the failure rate increases with increasing service life. This reliability value of 45.74% is below the Indonesian industry standard, which stipulates a minimum reliability limit of 70%, which is estimated to be achieved at a service life of approximately 1,862.6 flight hours. A reliability value of 70% achieved at 1,862.6 flight hours is recommended as the threshold for reliable service life and is used as a reference in determining preventive maintenance intervals.*

- *Qualitative analysis using the failure mode and effect analysis (FMEA) method indicates that the brush-worn failure mode carries the highest risk. This mode has the highest risk priority number (RPN) of 252, which is supported by historical data, representing 12 out of 20 cases. To address brush failure, which is the dominant factor in APU starter motor failures, a brush wear indicator can be implemented in accordance with the AMM.*

4.2 Recommendations

- *As a follow-up to this research, recommendations can be made for the company and for further research.*

- *Based on the MTTF value, the reliability level is 45.74% at 2,742.85 flight hours and with a clear estimate of component life, the logistics and procurement departments can more accurately plan the availability of spare parts for the APU starter motor. This will reduce the likelihood of aircraft on the ground (AOG) due to spare parts shortages.*

- *The maintenance team should focus on brush condition analysis based on FMEA results. This can be achieved by ensuring that brush wear indicator inspections are carried out in accordance with the AMM, and scheduled when the APU starter motor's reliability value reaches 70% within the component's operational life, or 1,862.6 flight hours.*

- *Similar research should be conducted not only at PT Indonesia AirAsia but also at other companies to obtain more up-to-date data.*

5. *REFERENCES*

[1]A. Fadhil dan H. Abu Bakar, Analisis Terjadinya Apu Auto Shutdown di Pesawat Airbus A320-200, *Indept*, vol. 5, No.1.

[2]A. Faizal dan S. Arifin, Analisis Keandalan Instrumentasi pada Unit Central Mechanical Electrical menggu nakan Metode Failure Mode and Effect Analysis (FMEA) (Studi kasus PT Telkom Area Network Riau Daratan Pekanbaru), Panam

[3]A. G. Firdaus dkk., Analisis Penyebab APU Auto Shutdown pada Pesawat

Airbus A 320, *Jurnal V-Mac*, vol. 9, No. 2, hlm. 46–55, 2024, doi: 10.36526/v-mac.v9i2. 4256.

[4]F. K. Rahmawati dan S. M. S. Mulyani, Reliability Analysis of Nose Wheel Assy ATR 72-500, *Conference SENATIK STT Adisutjipto Yogyakarta*, vol. 6, hlm. 27–34, Des 2020, doi: 10.28989/senatik. v6i0.404.

[5] F. Hakim Nasution, M. Syahran Jailani, and R. Junaidi, Kombinasi (Mixed-Methods) Dalam Praktis Penelitian Ilmiah,J. Genta Mulia, vol. 15, No. 2, pp. 251–256, 2024, [Online]. Available: https://ejournal.stkipbbm.ac.id/index.php /gm

[6]F. Rafsyan Zani and H. Supriyanto, Analisis Perbaikan Proses Pengema san Menggunakan *Metode Root Cause Analysis dan Failure Mode And Effect Analysis* Dalam Upaya Meningkatkan Kualitas Produk Pada CV. XYZ, *Semin. Nas. Sains dan Teknol. Terap. IX*, pp. 140–146, 2021.

[7]J. n W. Creswell dan Creswell David J, *Research Design_ Qualitative, Quantita tive, and Mixed Methods Approaches - creswell*.

[8]M. Waruwu, Pendekatan Penelitian Kualitatif: Konsep, Prosedur, Kelebihan dan Peran di Bidang Pendidikan, Penelitian dan Evaluasi Pendidikan, vol. 5, No.2, hlm. 198–211, 2024, doi: 10.596 98/afeksi.v5i2.236.

[9]Muhammad Masykur Huda, Analisis Keandalan T*urbocompresso*r P/N 222 2254-1 Boeing 777–300ER Menggu nakan Distribusi Weibull Dan Fault Tree Analysis di PT XYZ, Politeknik Pener bangan Indonesia Curug, Tangerang, 2024.

[10]N. L. Ahmad, F. Fatonah, dan S. Pur nomo, Analisis Pengaruh *Maintenance* Ter hadap *Performance Peralatan Doppler Very High Frequency Omnidirec tional Range* (DVOR), *G*-Tech: Jurnal Teknologi Terapan, vol. 7, No. 3, hlm. 1238–1244, Jul 2023, doi: 10.33379/ gtech.v7i3.2714.

[11]Nasywa Hafizah, Tiara Cantika Pebytabella P, Mutiya Sari, Rahmita Winanda, Rully Hidayatullah, dan H. Harmonedi, Identifikasi Variabel Penelitian, Jenis Sumber Data Dalam Penelitian Pendidikan, Jurnal QOSIM Jurnal Pendidikan Sosial & Humaniora, vol. 3, No. 2, hlm. 586–596, Mei 2025, doi: 10.61104/jq.v3i2.1025.

[12]R. B.Abernethy, *Reliability &statistical analysis for predicting life, safety, risk, support costs, failures, and forecasting warranty claims, substantiation and acce lerated testing, using Weibull, Log normal, Crow-AMSAA, Probit, and Kaplan-Meier models*, 5 ed. North Palm Beach: R.B. Abernethy, 2008.

[13]S. W. Purwanza, A. Wardhana, dan A. Mufidah, Metodelogi Penelitisan Kuanti tatif kualitatif Dan Kombinasi. Bandung: CV Media Sains Indonesia, 2022.

[14]T. Pramiyati, Peran Data Primer Pada Pembentukan Skema Konseptual Yang Faktual (Studi Kasus: Skema Konsep tual Basis Data Simbumil), Jurnal Simetris, vol. 8, No. 2, hlm. 679–686, doi: 10.24176/simet.v8i2.1574.

[15]UU No 1 Tahun 2009, Undang-Undang Republik Indonesia No 1 Tahun 2009. Indonesia. https://peraturan.bpk.go.id/Details/5465 6/uu-no-1-tahun-2009

[16]W. Vera Nurfajriani, M. W. Ilham, dan A. Mahendra, Triangulasi Data Dalam Analisis Data Kualitatif, Ilmiah Wahana

Pendidikan, vol.10, No.17, hlm.826–833,2024,doi:10.5281/zenodo.13929272.

[17]Y. K. Sakti, I. A. S. W, and D. Zuhroh, Analisis Faktor-Faktor Penyebab Ter hambatnya Perkembangan Umkm Sentra Ikan Bulak (SIB) Kenjeran Dengan Pendekatan Metode Fishbone Diagram, *Semin. Nas. Has. Penelit. dan Pengabdi. 2020*, pp. 92–99, 2020.

[18]Z. Ramadhana, *Modifikasi Failure Modes And Effect Analysis (FMEA) pada Rotor Turbin Pesawat Terbang Untuk Meningkatkan Efisiensi Manaje men Resiko* dan Keandalan, Institut Teknologi Sepuluh Nopember, Surabaya, 2021. Accessed: Mar. 09, 2025. [Online]. Available:http://repository.its.ac.id/id/eprint/83215