

IMPLEMENTATION OF MAINTENANCE SCENARIO FOR CRITICAL SUBSYSTEM IN AIRCRAFT ENGINE

Case study: NTP CT7 engine

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Abstract— An aircraft company needs to "secure" their aircraft engine for a good maintenance system to keep the optimum engine's performance during the flight. This paper proposed maintenance analysis and scenario for the CT7, the main engine for aircraft at NTP company. A failure data record from four critical components of the CT7 engine is analyzed using Reliability Centered Maintenance (RCM) and Risk Based Maintenance (RBM) methods to obtain the optimum maintenance interval task for the critical subsystem of the CT7 engine and also seeing the risk of maintenance cost of the engine's failure effect.

The RCM analysis result obtained seven scheduled on condition task, six scheduled discard task, and three scheduled restoration task. The interval of the maintenance schedule of each critical component varies according to the function obtained. And based RBM analysis, the risk from system performance loss is got \$ 7.014.841, 90. Meanwhile, the total cost of maintenance interval based on a calculation of optimal time interval got \$1.885.612, 82.

Keywords— preventive maintenance, reliability-centered maintenance, risk-based maintenance, risk priority number.

I. INTRODUCTION

Maintenance is an activity to restore function from machine or system into a standard role. A tool or system with running 24 hours a day need a good management system to optimize their result [1] According to [2], in the manufacturing area; all of the production machines must be monitored well to ensure the engine can run smoothly without any sudden breakdown. Instead of the manufacturing machine, the maintenance activities also performed in the transportation industry, one of them is air transportation, especially in aircraft engine's maintenance services [3].

D. Chen et al [4] stated that aircraft maintenance work includes pre-flight checks, post-flight inspection, and scheduled maintenance. Based on this paper, the statistic shown, only 60% of the total aircraft failure can be found with ground inspection, while 40% of the fault exposed during flight. Meanwhile, according to Kinnison [5] and Howlan et al. [6], the benefit of

interval maintenance checking along with the wear out conditions especially in aircraft component only got 11 % from total maintenance cost, the rest of 89 % when the failure occur, the maintenance schedule cannot apply. Moreover, the need for optimum maintenance interval schedule and a proper task for an aircraft engine are mandatory and essential in aviation management system. Furthermore, considering the maintenance cost effect which is coming from the failure of the engine during its operation, it's crucial to analyze the risk of engine failure by knowing the probability of failure and risk of system performance lost.

In this paper we propose an analysis of maintenance scenario for the critical subsystem in the CT7 engine using the Reliability Maintenance Centered (RCM) to find the optimal maintenance task and schedule, meanwhile the Risk Based Maintenance (RBM) method will analyze the engine failure based on the risk-based and cost of maintenance

This paper organized as follow, section two provides background and related research, part 3 contains the research methodology, chapter 4 shows the experiment result, and finally, the conclusion, discussion, and some remark presented in section 5.

II. BACKGROUND

In the aviation industry business, the safety of the customer during their flight is a critical point. To support this, the engine as a part for the aircraft must keep in excellent condition. The aircraft engine is the central part for the airplane which becomes a critical power for the plane. The excellent engine maintenance's system, the optimum live time can be used. Therefore, the maintenance department must ensure there is no trouble in the aircraft engine and provide the optimum maintenance schedule for this term.

NTP is one of the maintenance inspection and service's company for the aircraft engines. The engine

services include inspection services, changes (modification), minor repairs, and overhaul of turbine engines for aircraft. The air flight services company usually sent the aircraft engine to NTP to be checked and repair if there is any failure. There are various types of aircraft engines accepted by this company from 2012 to 2016. The kind of aircraft engine type which received from NTP customer shown in figure 1.

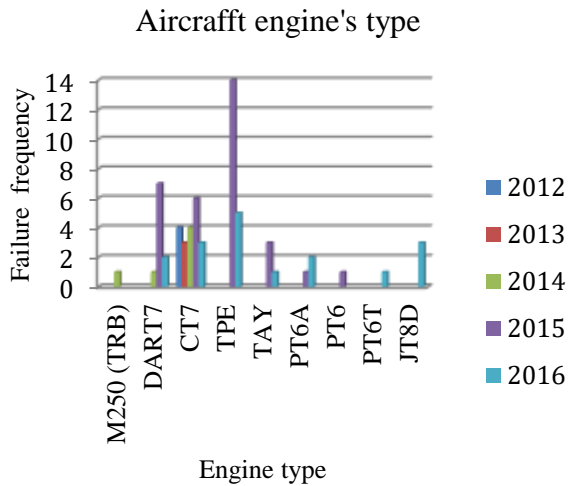


Fig. 1 Type and number of failure

Based on Fig. 1, it can be seen that from 2012 to 2016; the CT7 engine type got the highest failure frequency among the others type engines. The clarification and confirmation of the maintenance database for the CT7 engine in Maintenance department have done to find the total data downtime. The data downtime of the CT7 engine can see in Fig. 2.

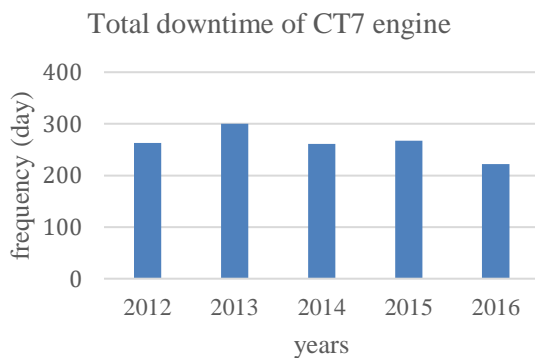


Fig. 2 Total downtime of CT7 engine

Fig. 2 shows that the downtime of CT7 engine is high enough for each year, from 2012 until 2016. Based on this data, the total downtime is relatively high. This data is the accumulation of data of downtime in several serial numbers of CT7 which sent to NTP each year. In fact, commonly the NTP's maintenance department

was undertaken services or overhaul maintenance for the CT7 engine after the damage occurred within a specified time interval (every 6000 hours flight). The high overhaul maintenance activities can lead to high maintenance costs, downtime and increased risk of loss due to decreased engine performance. Therefore, it is necessary to improve the maintenance activities more effectively for CT7 engine and also optimize the timing or interval of machine maintenance to have good availability and to reduce the potential for wrong types of maintenance activities as well as errors in the implementation of maintenance activities.

To keep the quality performance of an aircraft engine; the maintenance activity must be early stated strongly as major's preventive maintenance on the aircraft maintenance department. Preventive maintenance is all action taken in a planned, periodic, and specific schedule to keep the device in a prescribed operational condition, by going through the inspection and recondition process [7]. Determination of preventive maintenance policy also takes into account time interval. The time interval of care is used to determine when the machine should treat. One of the methods which can be used to analyze the interval maintenance schedule is using Reliability Centered Maintenance (RCM). RCM is a reliability-based maintenance where the approach assumes that maintenance cannot act more than ensuring that assets continue to achieve their necessary capabilities [7]. Regarding it, a complete understanding of RCM is a process used to determine what needs to be done to ensure that any physical asset can continue to meet the expected function in the context of its current operations. The primary objectives of RCM are to build priorities related to design that can support preventive maintenance activities and finally to obtain useful information to improve the component design with proven reliability, availability, and maintainability.

Ahmadi et al. [8] describe some aspects of how RCM and PHM (Prognostics and Health Management) are complementing each other and what kind of adaptations that have to be done to achieve a successful integration. The combination of this two methods is affected by the best maintenance tasks in the development of the initial maintenance program. A proper application of RCM early in system design might generate a pull for PHM-technology integration and motivate design changes of the aircraft. In connection with the capability of the maintenance team, Serdar [9] analyze the factor of maintenance training for the plane. It stated that aircraft maintenance is one of the leading causes or contributing factors in aircraft accidents, it is clear that right and proper training of Aircraft Maintenance Technicians (AMTs) will avoid failures, reduce maintenance-related accidents, improve safety and reliability in aviation [9].

The application of RCM in the aircraft operation by Beňo, Luděk et al [10], are presented in their research where stated that the RCM program provides a logical way of determining if preventive maintenance makes sense for a given part, system or the whole of aircraft. The RCM concept completely changes the way in which the preventive maintenance viewed.

Along with the RCM method, the other concern in the aircraft engine maintenance is the risk caused by the maintenance activity. One of the risk analysis is using the RBM. The RBM method is a quantitative method based on the integration of the approach between reliability and a risk approach strategy that aims to optimize the maintenance schedule and to minimize the risk posed by the failure [11]. The output of the RBM method is the value of the risk borne by the company if the system fails the function. The quantitative amount of risk is the basis for prioritizing maintenance and inspection activities. In general, the risk-based calculation is the result of probability failure multiplied by its consequence of system performance lost.

III. RESEARCH METHODOLOGY

As stated in the introduction, this research will focus on the CT7 engine, especially in the critical component of CT7 Engine. The primary failure data for this research is provided by NTP company, one of the aircraft engine’s maintenance services company. The failure data gathered from 2012 to 2016. The study started by obtaining data of Time To Repair (TTR) and Time To Failure (TTF) of the CT7 machine from database maintenance. TTR data is the time required to troubleshoot and repair failed equipment and return it to normal operating conditions [12]. Meanwhile, the TTF is the length of time a device or other product is expected to last in operation. The flow of the research methodology shown in Figure 3.

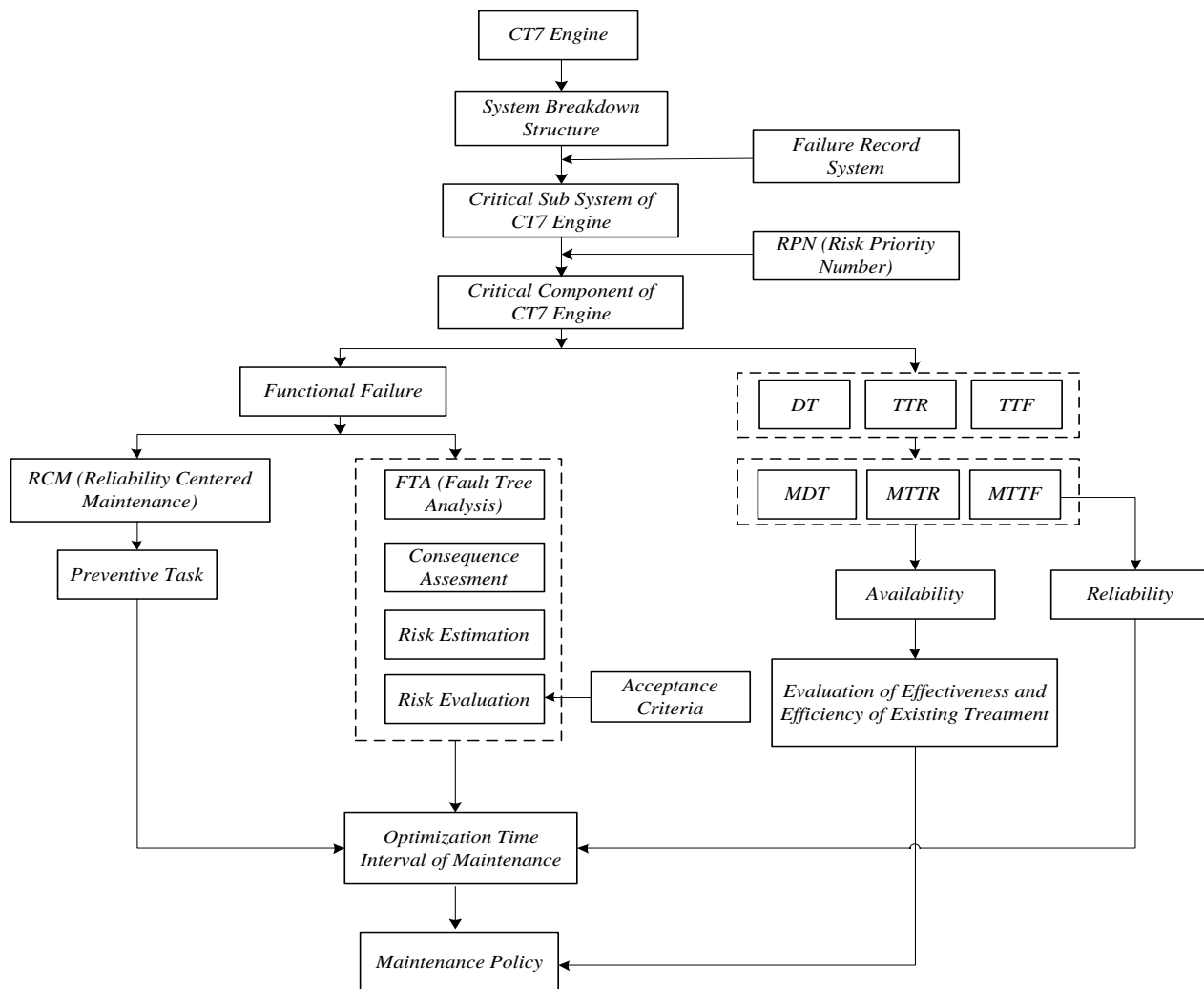


Fig. 3 Research methodology

Based on Fig.3, research methodology; the first step in this study is to determine the parts the CT7 machine that will be the focus and further analysis. System Breakdown Structure (SBS) machine must be done to facilitate the process of identifying parts of the machine. System Breakdown Structure (SBS) is a tool for analyzing, documenting and communicating machine structure at the system level, subsystems to components in detail and structured. SBS groups systems in equipment based on their function whereas the existing functional system can identify quickly. SBS is the first step that must be done to determine the components of a system for further more in-depth analysis [13]. SBS can also be used to identify the level at which failure occurs and to analyze its effect on related systems, subsystems or components. SBS provides a representation of parts of equipment in the form of interrelated diagrams based on their functions. How to analyze SBS is to divide the machine into several main components, such as electrical system, mechanical system, pneumatic system, hydraulic system, machine support system. From the main parts of the machine will be divided into more detailed parts or subsystems and parts. After SBS analysis performed, the next step is to determine the critical components or parts of the previous SBS frame.

The determination and selection of critical parts are using the Risk Priority Number (RPN) method. RPN is a method for identifying essential components or criticality of a system [14], [15]. Identification of criticality is required because not all equipment or machines have the same critical level. The impact of the failure also different levels of risk. Also, by identifying the criticality of a component, the company can determine the best maintenance strategy to be chosen. The stages for calculating the RPN are to do a total calculation between the three RPN factors, namely: severity, occurrence, and detection [16]. Severity, is the level of effect that will result from the failure or damage of the component, occurrence, indicates how often the failure or damage of the element appears, while the detection, showing how the probability of detecting a failure before the damage appears. The assessment of these three factors using a rating scale between 1-10 and a value of 10 means having a huge impact, often or even always occurs. These factors are multiplied, and a priority value will be obtained with the most significant component value

will require particular attention because it has the highest criticality level. After the critical system is obtained then two types of measurements made, namely qualitative and quantitative measurement. Both measurements refer to the functional failure (FF) of the critical component. In the qualitative analysis was done by determining preventive maintenance activities by the RCM (Reliability Centered Maintenance) method which aims to evaluate existing maintenance strategies and identify the proposed preventive maintenance activities. Another quantitative measurement is by using the Risk Based Maintenance (RBM) method. The method is used to calculate the level of risk that will be borne by the company in case of damage consisting of financial factors and system performance. This method begins with determining the Fault Tree Analysis (FTA), determining the consequences, estimating the risks and performing the risk evaluation. Whereas, the quantitative measurement starts by deciding Mean Downtime (MDT), Mean Time to Failure (MTTF), and Mean Time to Repair (MTTR) from time to failure (TTF) and Time to Repair (TTR) calculations done before. These measurements are used to calculate the availability, reliability and maintenance costs of critical components consisting of loss of revenue, engineer's wage, material cost and component cost. The comparison of availability used as a basis for evaluating the effectiveness and efficiency of existing maintenance activities. This evaluation is used to determine whether downtime is entirely used for repair of damaged components or used for inspection, logistics, and delay. In addition to being the basis of availability calculation, MTTF is used to determine the reliability of the critical components to determine the optimal preventive maintenance interval.

After finding out the cost of maintenance then the next stage is to estimate the total maintenance cost with the risk of damage among critical components. The total cost and risk will be used as the basis for optimizing maintenance time interval by considering component reliability value. The optimization result of the treatment time interval will be used as the basis for the evaluation of the maintenance activities to find out the comparison of effectiveness level and efficiency of maintenance activity of existing proposal by preparing the critical component maintenance policy of CT7 Engine.

IV. RESEARCH RESULT

There is some initial step to analyze the maintenance data of the CT7 engine, such as the following:

1. System Breakdown Structure (SBS)

Divide the hierarchical structure of the CT7 Engine machine into system level, subsystems, and components.
2. Determine the critical component by using Risk Priority Number (RPN) tools based on severity, occurrence and detection criteria.
3. Distribution plotting for TTF, TTR and DT data to obtain the data parameters based on representative distribution.
4. Collecting data

The data to obtained is cost data consisting of the component, material, labor, downtime, and maintenance of existing cost.



Fig. 4 CT7-9C Engine [17]

Figure 4. shows the illustration of the CT7 Engine for this research. Based on interview and confirmation from the Maintenance Department of NTP’s company; using the SBS system, there is thirty-five (35) primary part which constructed the CT7Engine. Figure 5. show he SBS structure of this engine; the “red block “ figure is the four critical subsystem based on RPN calculation which will be explained in section 4.1.

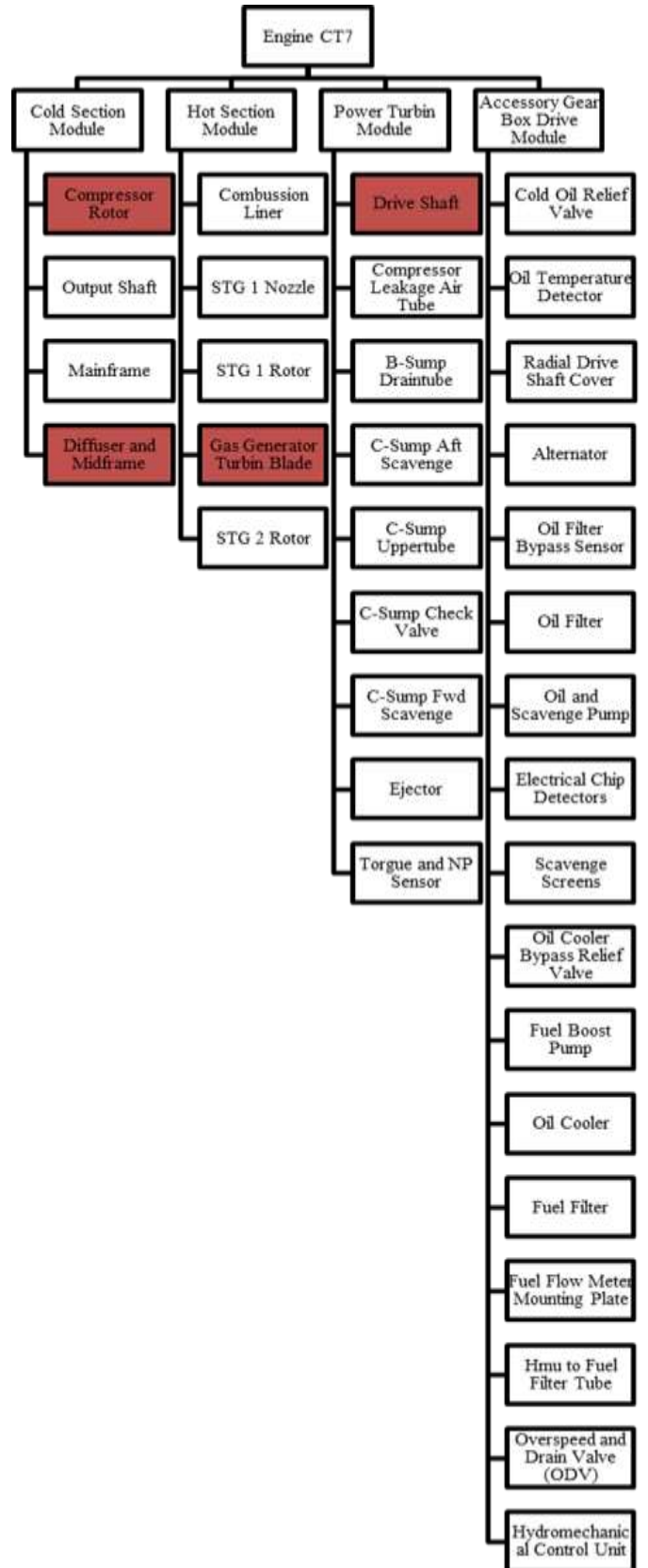


Fig. 5 System Breakdown Structure of CT7 Engine

4.1 Risk Priority Number Analysis

RPN (Risk Priority Number) result based on calculation the severity (S), occurrence (O) and detection (D) value, the factors are multiplied, and the priority value based on the greatest RPN component value [14]–[16]. The subsystem which has the highest criticality level will require particular attention and maintenance's priority. The following is the calculation result of the risk priority number.

Table 1. The RPN analysis result

No	Subsystem	S	O	D	RPN
1	Diffuser and Midframe Assembly	9	6	9	486
2	Gas Generator Turbine Stator Assembly	9	7	7	441
3	Compressor rotor assembly	9	8	6	432
4	Power Turbin Drive Shaft	9	5	9	405
5	Combustion Liner	7	5	7	245
6	Output Shaft Assembly	9	4	6	216
7	C-sump aft scavenge	8	5	5	200
8	STG 1 Nozzle	7	4	7	196
9	STG1 Rotor Assy	7	4	7	196
10	C-sump upper tube	7	5	5	175
11	STG 2 Rotor Assy	8	3	7	168
12	C-sump Check Valve	8	4	5	160
13	Oil Temperature Detector	8	4	4	128
14	Mainframe	7	3	6	126
15	Cold Oil Relief Valve	8	5	3	120
16	Radial Drive Shaft Cover	7	4	4	112
17	Compressor Leakage Air Tube	7	3	5	105
18	B-sump drain tube	8	3	4	96
19	Ejector	8	3	4	96
20	Alternator	8	4	3	96
21	Oil Filter Bypass Sensor	8	4	3	96
22	Oil Filter	8	4	3	96
23	Oil and Scavenge Pump	8	4	3	96
24	Electrical Chip Detectors	8	4	3	96
25	Scavenge Screens	8	4	3	96
26	Oil Cooler Bypass Relief Valve	8	4	3	96
27	Fuel Boost Pump	8	4	3	96
28	Oil Cooler	8	4	3	96
29	Fuel Filter	8	4	3	96
30	Fuel Flow Meter Mounting Plate	8	4	3	96
31	Hmu to Fuel Filter Tube	8	4	3	96
32	Overspeed and Drain Valve (ODV)	8	4	3	96
33	Hydromechanical Control Unit	8	4	3	96
34	C-sump Fwd Scavenge	7	2	5	70
35	Torgue and NP Sensor	8	2	3	48

Based on table 1. show that four subsystems have a high result of RPN calculations, compare the others. The subsystem is a diffuser and midframe assembly (midframe), gas generator turbine stator assembly (turbine blade), compressor rotor assembly (compressor rotor), power turbine drive shaft (drive shaft).

The result of RPN analysis also confirmed by Maintenance Department which stated that the four subsystems (midframe, turbine blade, a compressor rotor, drive shaft) were indeed categories as a high critical level because if the component is down, the CT7 Engine cannot work according to its performance. Also, these components are components that require extended lead time in spare parts procurement because currently, NTP implements zero inventory policy. Based on failure data record from the maintenance department the total downtime of four critical is shown in table 2.

Table 2. The downtime of critical subsystem

No	Critical subsystem	Downtime/ years (hours)
1	Compressor Rotor	1592,23
2	Mid Frame	1671,55
3	Turbine Blade	1590,82
4	Drive Shaft	1727,07

Table 2. show the total downtime of critical subsystem each year. The drive shaft got the highest downtime to compare the others. After the critical component (spares) is selected, then from the damage history data of each four-part later determined Mean Time To Failure (MTTF), Mean Time To Repair (MTTR), Mean Time Between Failure (MTBF). Mean Time To Failure is the average time interval of damage from a damage distribution, Mean Time To Repair is the average repair time of a component. Mean Time Between Failure is the inter-failure time or average time or failure expectation of a part operating under normal conditions.

There is several types of failure distribution function based on reliability that is often used to analyze maintenance problems such as Exponential distribution, Normal distribution, and Weibull distribution. Failure data from the critical components are analyzed using Minitab 17 and AvSim 9.0 software to determine the type of distribution of the damage. Software Minitab 17 and AvSim 9.0 is one software to calculate and determine the kind of distribution that represents the failure that exists in the critical components of the machine. The next step is processing and data analysis using (Reliability

Centered Maintenance) and Risk Based Maintenance (RBM)

4.2 Reliability Centered Maintenance (RCM)

Quantitative measurements using RCM are used to determine the proper maintenance activities for the CT7 engine critical components. To find out the failure mode and the impact caused by the failure of the essential elements of the CT7 engine, Failure Mode and Effect Analysis (FMEA) was determined. Then next determine the Logic Tree Analysis (LTA) used to classify the consequences of failure mode. LTA is used to determine the appropriate preventive task for each component through the RCM decision diagram. From the results of the RCM decision diagram, there are two types of scenario preventive maintenance:

1. Scheduled On Condition Task

The calculation of time interval for maintenance task Schedule on condition is half from P-F interval of each critical subsystem. The P-F interval defined as the interval between the occurrence of a potential failure and the failure condition of the functional equipment [7]. The following is the result of proposed maintenance scheduling and proposed task for each critical subsystem based on the scheduled on condition task.

Table 3. The schedule on condition task

Critical subsystem	Proposed task	Maintenance interval (hours)
Mid-frame	Cleaning and coating	660
Compressor rotor	Cleaning and coating	318
Turbine blade	Material checking	394
Driveshaft	Cleaning and coating	759

Table 3, shows that each of subsystem has each maintenance proposed task and each interval maintenance; for example Mid frame, a proposed task is cleaning and coating, and the maximum interval is every 660 hours.

2. Schedule Restoration and Discard Task

Schedule restoration is an effort to restore the machine, subsystem or component of the existing in a periodically time with the aim is restoring the system to its original state. As for the schedule, discard requires to replace the critical parts before the subsystem's live time limit with regardless of the current condition of the part itself. The following is the

calculation of the scheduling of maintenance for schedule restoration and discard task.

Table 4. The restoration and discard task

Critical subsystem	Proposed task	Maintenance interval (hours)
Mid Frame	Repair the deformation material and replace the seal	1408
Compressor Rotor	Replace the rotor	714
Turbine Blade	Replace the blade	877
Driveshaft	Repair and check the torque design and accuracy	1663

Table 4, shows the interval of restoration and discard task for the critical subsystem. From this table, show that the job was consist of two main work which is repair and replaces. This means that the subsystem needs more attention and maintenance activity if compare with the schedule on condition task previously. For example Mid frame, the proposed mission is to repair the deformation material and also replace the seal with a maximum interval is every 1440 hours. It's mean, every 1440 hours the midframe must repair and replaced regularly to minimize the sudden failure.

3. Preventive maintenance cost

To compare the effectiveness of the proposed maintenance task with the actual maintenance cost, it's essential to calculate the total maintenance cost for the critical subsystem.

a) The existing maintenance cost

In the existing the calculation of maintenance costs; it is carried out over a period of 6000 hours and itis adjusted if less than 6000 hours; there are components to be replaced. The total calculation cost of maintenance overhaul activities assumed that maintenance activities are carried out for 90 to 120 days and maintenance time per day is 8 hours. Its considered the overhaul has done for 15 times in a year. The total maintenance cost is the result of maintenance cost multiplied by maintenance frequency, and the result is \$ 3.470.965.

b) The scenario of propose maintenance cost

The proposed maintenance cost is based on pre-determined maintenance policies and adjusted to the intervals of each critical component. The variety of

proposed task will automatically effect into the total of maintenance cost as shown in table 5.

Table 5. The propose maintenance scenario cost

Critical subsystem	All of the proposed maintenance task	Maintenance cost
Mid-frame	Cleaning, coating, repair the deformation material, replace the seal	\$ 564,455.40
Compressor rotor	Cleaning, coating, replace the rotor	\$ 712,714.80
Turbine blade	Material checking, Replace the blade	\$ 538,393.39
Driveshaft	Cleaning, coating, repair and check the torque design and accuracy	\$ 68,321.54
Total maintenance cost		\$1,885,612.82

Based on table 5, the total maintenance cost for the four critical subsystems CT7 is \$1,885,612.82. This value is lower than the current overhaul maintenance cost which has done at NTP.

4.3 Risk Based Maintenance (RBM)

RBM analysis aims to reduce the risks affected by failures in operating facilities. The first step used in the calculation by this RBM method is to set up a failure scenario for four critical subsystems. The failure scenario of this shown in table 6.

Table 6. The failure maintenance scenario

Critical subsystem	Probability of failure	Failure effect
Mid-frame	High temperature, high airspeed, high turbine rotation, material friction	Seal not working, inhibits airflow, low efficiency
Compressor rotor	Foreign object infiltrate, spinning friction, high-pressure friction	Disrupted performance, decreases efficiency, broken and stuck a compressor
Turbine blade	Blade fracture, foreign object infiltrate, high blade pressure	Decreases performance and efficiency, broken blade and compressor
Driveshaft	Low accuracy, friction when spinning, improper shaft design	improper torque result, the turbine does not rotate

properly, performance decreases

Table 6 shows the failure scenario of each CT7 critical subsystem. Several probabilities were presented to obtain the failure effect of the subsystem. The failure that occurs in the CT7 engine gave consequence in the form of system performance loss and does not cause significant impact to human health loss, financial loss, and environmental loss.

After setting up a failure scenario, then the next steps are to determine the quantification of consequences that occur due to the functional failure. In the critical component of CT7 Engine the operational failures that occur only lead to failure of the operating system and the decline in system work resulting in the emergence of losses such as losses due to failure and the development of additional maintenance costs. The consequences of system performance degradation for each failure scenario need to be normalized to find out how significant the risk caused by the failure is determined based on the failure scale.

After the probability of failure for each critical component has determined, then calculate the final risk of this failure. The calculation of the risk of damage to CT7 Engine critical components obtained from the value of System Performance Loss multiplied by the probability of the part failing over the five-year interval. The result of risk calculation presented in table 7.

Table 7. The risk based maintenance cost

Critical subsystem	Risk based maintenance cost
Mid frame	\$1,777,975.02
Compressor rotor	\$1,732,794.60
Turbine blade	\$1,729,392.79
Drive shaft	\$1,774,679.49
Total risk	\$7,014,841.90

Based on table 7 the calculation, the total risk-based maintenance of critical subsystem is \$ 7.014,842. Must be noted in clearly that this cost came up if there are any preventive maintenance activity.

V. CONCLUSION

The implementation of overhaul maintenance sometimes passes the predefined time standard. This scenario is due to new defects identified during disassembly which increasing the maintenance time of the scheduled. These maintenance activities are considered not effective and efficient because it still

causes a lot of lead time and maintenance time is not following the scheduled.

The aviation industry, with high requirement of safety and reliability, need the proper of maintenance activity and schedule. Therefore, maintenance activities need to be improved, especially for critical components of an aircraft engine. Improvements include the type of task performed and the interval of the maintenance schedule. In this paper, we proposed the maintenance scenario analysis for critical aircraft subsystem using Reliability Maintenance Centered (RCM) and Risk Based Maintenance (RBM) which considering the task and time interval of the maintenance refer to the characteristics of the cause of damage and the time between the damage of each critical component. The risk-based maintenance analysis presented here to show the effect of critical subsystem failure for the whole maintenance cost.

The optimal maintenance time interval is the time interval that results in a minimum total cost and risk and a high-reliability value. It is a challenging issue to synchronize between two interest due to flight schedule and the maintenance schedule. Furthermore, the need for subsequent research on the optimal spare parts procurement for these critical components of the CT7 engine is important to support the optimum maintenance schedule.

REFERENCES

- [1] F. T. D. Atmaji, "Optimasi Jadwal Perawatan Pencegahan Pada Mesin Tenun Unit Satu Di PT KSM, Yogyakarta," *J. Rekayasa Sist. Ind.*, vol. 2, no. April, pp. 7–11, 2015.
- [2] J. Alhilman, F. T. D. Atmaji, and N. Athari, "Software application for maintenance system: A combination of maintenance methods in printing industry," in *2017 5th International Conference on Information and Communication Technology, ICoIC7 2017*, 2017.
- [3] Q. Li, D... Feng, and Z. Mei, "Aircraft configuration management and retrospective in life cycle," *Jisuanji Jicheng Zhizao Xitong/Computer Integr. Manuf. Syst. CIMS*, vol. 22, no. 2, pp. 476–481, 2016.
- [4] D. Chen, X. Wang, and J. Zhao, "Aircraft maintenance decision system based on real-time condition monitoring," in *Procedia Engineering*, 2012, vol. 29, pp. 765–769.
- [5] H. A. Kinnison, "Aviation Maintenance Management," *McGraw-Hill*, 2004.
- [6] S. Howlan, "Reliability-Centred Maintenance (RCM)," *Aircraft Engineering and Aerospace Technology*, vol. 53, no. 8. pp. 11–13, 1981.
- [7] J. Moubray, "Reliability centered maintenance," *Handbook of Maintenance Management and Engineering*. pp. 397–415, 2009.
- [8] A. Ahmadi, T. Fransson, A. Crona, M. Klein, and P. Söderholm, "Integration of RCM and PHM for the next generation of aircraft," in *IEEE Aerospace Conference Proceedings*, 2009.
- [9] S. Dalkilic, "Improving aircraft safety and reliability by aircraft maintenance technician training," *Eng. Fail. Anal.*, vol. 82, pp. 687–694, 2017.
- [10] L. Beño, M. Bugaj, and A. Novák, "Application of RCM principles in the air operations," *Komunikacie*, vol. 7, no. 2, pp. 20–24, 2005.
- [11] N. S. Arunraj and J. Maiti, "Risk-based maintenance - techniques and applications," *J. Hazard. Mater.*, vol. 142, no. 3, pp. 653–61, 2007.
- [12] M. Faccio, A. Persona, F. Sgarbossa, and G. Zanin, "Industrial maintenance policy development: A quantitative framework," *Int. J. Prod. Econ.*, vol. 147, pp. 85–93, Jan. 2014.
- [13] B. S. Blanchard and W. J. Fabrycky, *Systems Engineering and Analysis*. 2006.
- [14] Y. Fan, "Study of a new Analysis Method of Risk Priority Number Based on FMEA," *SAE Tech. Pap.*, vol. 2015–April, no. April 2015.
- [15] F. Zammori and R. Gabbrielli, "ANP/RPN: A multi-criteria evaluation of the risk priority number," *Qual. Reliab. Eng. Int.*, vol. 28, no. 1, pp. 85–104, 2012.
- [16] N. Sellappan and R. Sivasubramanian, "Modified Method for Evaluation of Risk Priority Number in Design FMEA," *ICFAI J. Oper. Manag.*, vol. 7, no. 1, pp. 43–52, 2008.
- [17] H. Aydin, O. Turan, A. Midilli, and T. H. Karakoc, "Exergetic and exergo-economic analysis of a turboprop engine: a case study for

CT7-9C,” *Int. J. Exergy*, vol. 11, no. 1, p. 69,
2012.