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Analysis of Changes in ACM Performance in PK-XXX Aircraft with Modification of Cleaning Method to Get a Comfortable Temperature

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Abstract
Airplanes are a mode of transportation that people are interested in because they have a relatively short travel time and long distances. Therefore, aircraft is a means of transportation with a high level of safety. One level of safety comes from the aircraft's Air Conditioning (AC) system, which functions as a temperature controller for the aircraft during flight and as a pressure protector during flight. Various components make up an aircraft AC system, one of which is the Air Cycle Machine (ACM). Where the ACM changes the temperature to extremes from hot to cold, the ACM becomes fouling, thereby reducing the performance of the ACM itself and causing an increase in the cabin temperature of the aircraft. This problem was solved by a different cleaning method, first using Aluminum Solution and second without using Aluminum Solution. The difference in cleaning methods aims to determine the right cleaning method to overcome the existing problems. The results showed that power without using aluminum solution gave 49.802 kJ/s in 5 minutes and 54.771 kJ/s in 10 minutes, while power using aluminum solution showed 40.1705 kJ/s in 5 minutes and 61.4155 kJ/s in 10 minutes. This indicates that the use of Aluminum solution requires greater power after the ACM rotates for 10 minutes, affecting the efficiency of the ACM itself. The results prove that the cleaning method without aluminum solution gives results of 140.6% at 5 minutes and 90.34% at 10 minutes compared to before.

Keywords:
Air Conditioning;
Air Cycle Machine:
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Fouling;
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INTRODUCTION

Air Conditioning (AC) is one of the essential AC systems in aircraft and is a system to support the comfort and safety of airplane passengers [1, 2, 3]. In addition, AC functions to regulate pressurization and as a regulator for temperature in the aircraft [4, 5, 6]. When an airplane is in flight, of course, it is necessary to maintain that the pressure in the aircraft must match the outside pressure so that the aircraft does not break. Besides, the air exchange must continue so that the air in the aircraft cabin remains fulfilled for the passengers. Therefore, knowledge of the correct function of the components will increase safety and considerably reduce the cost of maintenance operations [7][8].

In the aircraft, the AC system is divided into two parts, where each part is regulated by each series of the AC system. The two-part division is based on the zone in the aircraft, for part one consists of the cockpit zone and the forward galley and part two consists of the cabin zone, as well as the aft galley [9][10]. Each part previously mentioned is arranged in a series of systems consisting of several components that function to reach the desired temperature. There are many components such as heat exchangers, condensers, water extraction, reheater, and itself or known as the Air Cycle Machine (ACM). The energy to drive this machine comes from the compressed air bleed from the compressor of the aircraft propulsion turbine [9].

ACM has to change the hot pressurized air that can be sourced from the Auxiliary Power Unit or the engine during in-flight to a temperature of up to 0° C. ACM is divided into two parts: the hot section, which receives hot air and then compresses it using a compressor, and the cold section, where the warm air is lowered using a turbine [11, 12, 13].

The AC system keeps the compressed air in the fuselage compartment at the correct pressure, temperature, and freshness. Under normal conditions, the pneumatic system supplies air to the AC system from Main Engine Compressor, APU compressor and another high-pressure air supply unit [11, 12, 13].

The hot compressed air is cooled, conditioned, and supplied to the fuselage or cabin compartment and then exhausted to the ambient air via the exhaust flow valve and can also supply Air-Conditioned air to the distribution system via a low-pressure ground connection [13]. AC uses several components and several systems to take heat from compressed air, including AC/Control Panel, compressed air, Air Controller and Shutoff Valve, Heat Exchangers (Primary and Secondary), ACM, Ram Air System, Low Limit System (35F) and Water Separator. The work of the AC cycle is shown in Figure 1.

RAM air enters through the ram air inlet and bleeds air from the APU or engine, enters the primary heat exchanger inlet and then exchanges heat before entering the ACM (Impeller Wheel). Bleed air then rotates the Impeller Wheel and Exducer. This rotation causes a decrease in the temperature originating from the Impeller Wheel, which is then lowered back using air from the secondary heat exchanger before entering the Exducer. In the Exducer, the cold air is changed to close to 1°C. Therefore, the ACM changes the hot air to extreme cold. The function of the mixing valve is to prevent frozen air from entering the cabin by mixing hot air (bleed air) from the primary heat exchanger.

The purpose of the ACM is to reduce the air temperature due to expansion into the turbine. The location of the ACM is included in the AC compartment. There are two ACMs on the left and right [9]. The ACM is a component that rotates with high rotation. In ACM, three parts are related to the shaft: the turbine, compressor, and impeller fan. The water foil bearings help the shaft. Air bearings help ACM to rotate quickly but have little friction.

AC systems use a cooling turbine to cool pressurized air and deliver pressurized cold temperatures for cooling the aircraft cabin [14]. The cooling turbine has a bootstrap expansion type. The cooling turbine is mounted on the opposite end of the main shaft. The main shaft rotates on two spring annular ball bearings. The impeller wheel is covered by a scroll, while a torus covers the turbine wheel. The main housing encloses the main shaft and ball bearing. Figure 2 shows a cooling turbine Diagram.

The Main engine bleeds air that flows compressed air is routed through a primary heat exchanger where the main engine bleed air has been partially cooled by ram water or ambient air.

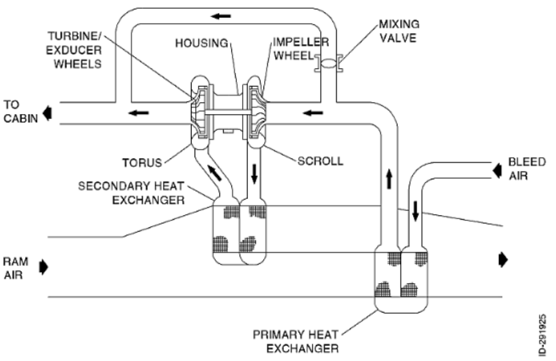

Figure 1. AC Cycle [9]

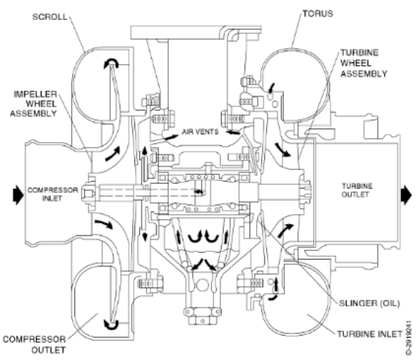

Figure 2. Cooling Turbine Schematic Diagram [9]

Main engine bleed air, which flows air, leaves the primary heat exchanger and enters the turbine blades of the compressor section. The air coming from the main engine bleed air is compressed by the compressor, increasing the pressure and also causing an increase in the air temperature of the bleed air. Bleed water then leaves the turbine compressor section and enters the secondary heat exchanger, which the water ram will also cool. Bleed water then exits the secondary heat exchanger and enters the turbine blades of the Exducer wheels. Compressed air is caused to spread rapidly in the turbine blades and causes a drop in air temperature. The rapidly dispersing air then leaves the turbine blades from the Exducer and enters the cabin AC control system. The compressor provides pneumatic energy for the AC system and turbine operation. Bleed water that is compressed in the compressor section is transferred to cooled air quickly for the AC system and mechanical energy for the turbine to operate.

The workload of the turbine section is required to maintain the efficient operation of the compressor part controlled by the mixing valve. The mixing valve controls the speed of rotation of the coolant turbine within the compressor part range and the efficiency of the turbine section. The Mixing valve is also used to reduce or increase air temperature to maintain the aircraft cabin temperature requirements. Opening the mixing valve causes the amount of the main engine bleed air that enters the compressor not high and mixes it with the output portion of the Exducer operation itself. This action causes a reduction in turbine rotation and an increase in air temperature in the turbine section. Closing the mixing valve causes all main engine bleed air to enter the compressor. This action causes an increase in turbine rotation and a decrease in air temperature at the turbine outlet. At this stage, the data that has been previously obtained are then processed by numerical calculation methods to determine changes in the cooling turbine itself. The test was carried out on a Boeing 737-500 aircraft cooling turbine with PK-XXX registration, which was carried out based on the Component Maintenance Manual manual. The test will be carried out twice, which is carried out before treatment and after treatment.

Turbine Cooling Efficiency is the value obtained from the temperature reduction results carried out by the turbine, or the turbine's ability to produce cold air, which will later be distributed into the aircraft cabin. The aircraft cabin reaches the requested cold temperature either when on the ground or when in flight later [9]. Turbine Cooling Efficiency is the value obtained from the temperature reduction results carried out by the turbine, or the turbine's ability to produce cold air, which will later be distributed into the aircraft cabin. The aircraft cabin reaches the requested cold temperature either when on the ground or when in flight later [9]. In the ACM calculation below, we only review the efficiency and work of the turbine so that this calculation only looks at points 6 and 7. This limitation is done because the cold temperature that enters the aircraft cabin comes from the expansion of the turbine, which changes the hot temperature to cold. Illustrations and T-s Diagrams can be seen in Figure 3.

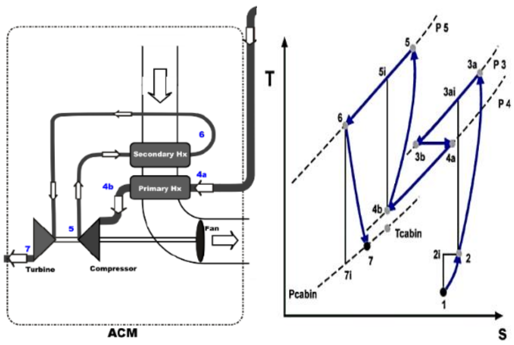

Figure 3. Illustrations and T-s Diagrams [9]

Then the formula used to find the temperature T_{7i} can be calculated by [9]:

$$\frac{T_{7i}}{T_6} = \left(\frac{P_7}{P_6}\right)^{k-1/k} \quad (1)$$

Then find the value of the isentropic turbine efficiency using the formula which can be found by:

$$\eta t = \frac{T_6 - T_7}{T_6 - T_{7i}} \quad (2)$$

While the work of the ACM turbine can be calculated in a way :

$$W_t = \dot{m}\, C_p\, (T_6 - T_7) \quad (3)$$

$$W_t = \dot{m}\, C_p \left(T_6\left(1 - \frac{P_7}{P_5}\right)\right)^{k-1/k} .\eta t \quad (4)$$

Description:
W_t : Work Turbine
$\dot{m}$: *mass flow rate*
ηt : Efficiency Turbine
C_p : Constant Pressure
k : Specific Heat on Constant Volume

ACM is an important component in maintaining the temperature in the cabin in a safe and comfortable condition, but if the performance of the ACM decreases due to fouling in the ACM, then proper maintenance is needed to maintain and improve the performance of the ACM in good condition, so thereby reducing maintenance costs.

METHOD

Material

The research approach is a method used to bring a problem under study so that it can explain and discuss the problem appropriately. This study uses a descriptive research method by comparing several AC systems commonly used in aircraft seen from the efficiency of the cooling turbine and maintenance methods to obtain the optimal AC system.

Data Collection

Use of Aircraft.

This data will show that the average aircraft operates in one cycle using the number of flights and routes taken in one day. Therefore, the aircraft is used in one day four times, and it can be interpreted that the plane takes about 120 flights in one month.

Component Specification

Passengers can feel the cold temperature through several existing components. Each component has its specifications. This journal focuses on the specification of cooling turbines (gas turbines) which have an airflow of 85.4 to 90.6 lb/min (39 to 41 kg/min) [15][16].

Cleaning Method

Based on the Component Maintenance Manual, the cleaning modification method can determine and influence the results of the level of efficiency in this study, making two modifications, namely using Aluminum Solution and without using Aluminum Solution, to provide how much difference in efficiency can be. Aluminum Solution is one of the methods used in the ACM cleaning process. This process is used by adding material powder by spraying on components that have been cleaned using chemicals. This process can help cover small holes in the skin Exducer and impeller due to fouling. After the second cleaning chemical process, the powder material will stick to the skin impeller and Exducer [17][18].

Cooling Efficiency

The results of the turbine cooling improvement have been determined in the component maintenance manual. The data is obtained to find out what percentage of the increase in the efficiency of the component is and to increase the accuracy. Numerical calculations are carried out to determine the results of this efficiency [19][20].

Methods

The research workflow in this case analysis of the reduction in turbine efficiency in the ACM component for PK-XXX aircraft to obtain a comfortable temperature in the cabin for a narrow-body Boeing 737-500 aircraft consists of several stages: follows the initial preparation stages, and the data collection stage.

The initial preparation stages

At this stage, it explains the search for literature which includes: ACM for Boeing 737-500 aircraft, materials and properties of the types of materials used by ACM, heat transfer and cooling systems. After that, all materials will affect the cabin cooling process using ACM and parameters that affect the process, such as how it works, main and supporting components, and other relevant things supporting this final project's writing. After the literature study, field observations were conducted—several surveys and discussions with those who are experienced and know about ACM as a whole.

The data collection stage

Data collection and collection were carried out at GMF AeroAsia. The data obtained at GMF AeroAsia are as follows:

- ACM:
  The data taken include:
  a. General description of ACM.
  b. ACM components.
  c. The function of each component.
  d. Operation ACM

- Maintenance management:
  a. ACM maintenance management type.
  b. A lifetime of the average ACM component, especially in the Exducer section.
  c. Component replacement management in ACM.

- The data review stage
  Based on the data that has been obtained regarding the main object (mainstream), then tracing and reviewing the data is carried out then tracing and reviewing data is then carried out to plan the design and analysis of the towing bar. The things that need to be considered are as follows: how ACM Works, ACM components, the function of each of the constituent

components of the ACM, ACM maintenance management type and the lifetime of an ACM average.

- The ACM planning stage is based on the data that has been obtained.

After knowing how the ACM works, component characteristics, ACM specifications, and maintenance management, the causes of ACM performance decline are planned. The steps taken are:

a. Selection of the appropriate devices or components.
b. Make a flow chart of the whole ACM work operation.
c. Calculating according to the data obtained

- The completion stages.

In this stage, the conclusions are explained while working on this final project and preparing the report. Therefore, the stages carried out while working on the final project, starting from a literature study, data collection, analysis, drawing conclusions, and preparing reports, can be explained in Table 1.

The flow chart of this research methodology can be seen in Figure 4.

Table 1. Completion Stage

No.	Process	Information
1.	Literature study and field observations.	A literature search includes ACM, materials and processes that occur in ACM, and parameters that affect the process, such as how it works, the main and supporting components and other things that support the writing of this final project.
2.	ACM planning	Study the heat transfer, material characteristics, and other things that support ACM planning.
3.	Making the layout and work system of ACM	Explains how ACM works in more detail. This process facilitates the preparation of the ACM work process.
4.	Calculation of heat transfer and cleaning effect	Explain specifically using numbers and formulas related to heat transfer in the ACM during operation and the effect of cleaning on component lifetime and the performance of the ACM itself.
5.	Preparation of reports	Make conclusions during the work of the final project and suggestions for further improvements.

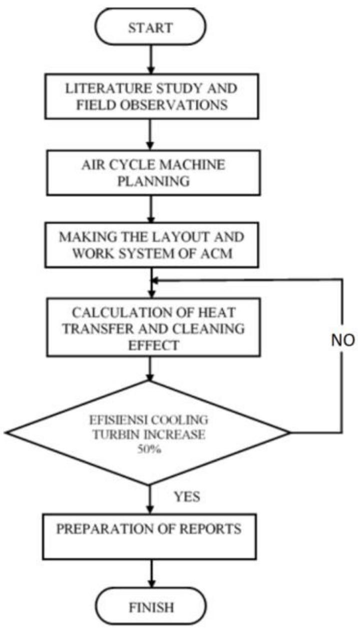

Figure 4. Flowchart of research methodology

RESULTS AND DISCUSSION

Cooling Turbin

Treatment of air from hot temperature to cold temperature is the task of cooling the turbine itself. Following the description, turbine cooling has a fairly large function. Besides that, the cooling turbine functions to produce cold air. The turbine cooling also functions to regulate the pressure in the cabin and provide fresh air to the aircraft cabin. This big task is that the turbine cooling is expected to be in prime condition because of the need for good preventive maintenance and good data collection to work optimally.

One of the important factors in routine cooling turbine maintenance activities is the cleaning process or cleaning each component of the cooling turbine itself, such as the impeller, turbine wheel, Exducer, and so on, to produce optimal performance.

Selection of Testing

This study will explain the role of the cleaning function on the effect of the performance of the cooling turbine itself. Therefore, cleaning modifications will be carried out and tested with two different types of tests, namely balancing to find out the cleaning results. Then, the final test will be to determine the overall performance of the treatment results.

Balancing Test

This test aims to determine the tolerance value obtained when performing a variation cleaning process with the aluminum solution and without an aluminum solution. Figure 5 shows the balancing test process.

Final Test

This test is carried out to find out the performance data of the cooling turbine obtained during the test. Some tests include the value of the turbine inlet and outlet temperature, rpm, oil leakage, and some other important data. The data will be used for calculations to find the efficiency value of the cooling turbine itself. The final test result is depicted in Figure 6.

Figure 5. Balancing Test

Figure 6. Final Test

Figure 7. Cleaning without Aluminium Solution

Figure 8. Cleaning with Aluminium Solution

Cleaning and Balancing Test Results

In the results of cleaning modifications in section 2, different specimens give different results. For example, without an aluminum solution, the dirt on the specimen surface cannot be completely removed in the cleaning method. However, it is different in the second specimen, which uses aluminum solution in the cleaning method. As a result, the dirt in the second specimen can be lifted completely and gives better results than in the first specimen. The cleaning process result comparison is shown in Figure 7 and Figure 8.

Final Test Result

In the final test results, all components that have been cleaned in the cleaning stage are assembled and then run using the test stand provided based on the component maintenance manual. This final test is a test that has been conditioned like the conditions when the components were installed on the aircraft. This test aims to determine the performance of the ACM by taking inlet and outlet temperature data on the ACM and then processing it to get the power and efficiency of the ACM using gas turbine calculations. The data is taken when the ACM has been running for 5 minutes and 10 minutes. The testing process was carried out twice, then averaged to obtain cooling results before and after cleaning with Aluminum Solution or without Aluminum Solution. The result of this test is listed in Table 2.

Table 2. Test results using running tests

	5 minutes	10 minutes
Before Cleaning	33,796 kJ/s	54,771 kJ/s
After Cleaning without Aluminium Solution	49,802 kJ/s	61,4155 kJ/s
After Cleaning with Aluminium Solution	40,1705 kJ/s	61,755 kJ/s

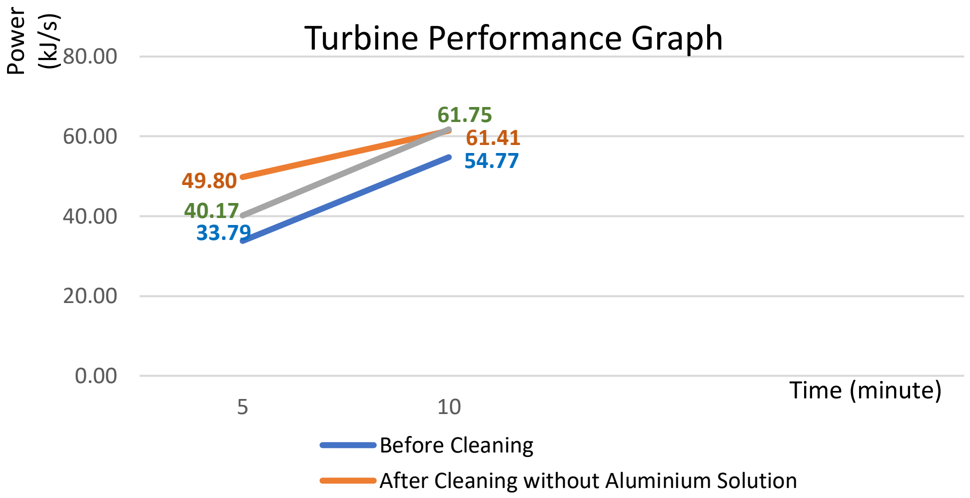

Figure 9. Turbine Performance Graph

Efficiency Cooling Turbin without Aluminium Solution, with:

$$\eta_{turbine} = \frac{\eta_{turbin1}}{\eta_{turbin\ 2}}$$

So, $\eta_{turbine}$ for 5 minutes is 140.6% and $\eta_{turbine}$ for 10 minutes is 87.9%. In addition, Efficiency Cooling Turbin with Aluminium Solution $\eta_{turbine}$ for 5 minutes is 133.71% and $\eta_{turbine}$ for 10 minutes is 90.34%. Figure 9 shows the turbine performance graph

Based on the temperature obtained at the time of testing using a test stand for the cleaning stage without Aluminum Solution and with Aluminum Solution, the power that has been shown in tables and graphs is obtained. The power for cleaning without Aluminum Solution at 5 minutes is 9.6 kJ/s better than cleaning with Aluminum Solution, while at 10 minutes, cleaning using Aluminum Solution gives 0.2 kJ/s better than without Aluminum Solution. The cooling turbine efficiency calculation shows the same results at 5-minute cleaning without Aluminum Solution showing 6.9% better than with Aluminum Solution, and at 10-minute cleaning with Aluminum Solution showing 2.4% better than cleaning without Aluminum Solution.

CONCLUSION

Based on the cleaning, balancing test, and final test results, it can be concluded that specimens using the aluminum solution give better results than those without using the aluminum solution. In addition, the final test shows a significant performance before and after treatment results are much improved after treatment.

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