PREDICTIVE & DETECTIVE MAINTENANCE:
EFFECTIVE TOOLS IN THE MANAGEMENT OF AERONAUTICAL PRODUCTS.

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Abstract

This literature review, analyze the development of maintenance models, in order to evaluate the current techniques employed in the preservation of aircraft. The study is based on the development of preventive maintenance which enabled the development of predictive maintenance techniques and detective. Currently used by major operator's worldwide aviation, these tools made it possible to increase security in air activity and enabled the implementation of more effective strategies to control the cost of operating aircraft to the world. The various types of tools used in the prediction and detection of malfunctions assist not only in preventing failures but also in the opposite direction to degradation diagnostic, being able to ensure that components and expensive parts that still have safe use conditions are discarded prematurely, based only on the preventive and statistical nature of recommendations.

1. Introduction

Business competition in the XXI century is present in all aircraft industries, being competitive has become a must condition for organizations to achieve success. Often the strategies of competitiveness, through product innovation and its production processes, in the acquisition of raw materials, supplies, among others. In today's competitive market, owners and operators are continuously searching for ways to reduce costs while maintaining safety.

An aircraft on the ground isn't making money. In the past, airlines have spent millions refining ground operations in the hope that even minimal improvements to maintenance processes, costs and quality might reduce the time equipment spends out of service [1].

The aircraft maintenance industry is one of the biggest contributors to the success of any airline. This sector encompasses several verification and repair activities that require equipment and personnel qualification to carry out its activities. Aeronautical maintenance is critical to the safety of aircraft operations in the transportation of cargo and passengers around the world. Considering the significant increase in the number of flights and increasingly restricted rules imposed by the aeronautical authorities, it is also an essential tool for aircraft manufacturers to improve their products and produce aircraft with higher levels of safety.

The globalized world where airlines began to work at reduced margins in the face of constant pressure from competitors, made them require manufacturers, safer, more technology-intensive aircraft [2].

The increase in air traffic and consequent reduction in the time between flights performed by the same aircraft increases the pressure by reducing the number of stops for maintenance activities. Thus, the effective management of maintenance in the aviation supply chain must be considered [3]. Major findings show that there is information about new trends in the aviation maintenance procedures that correlate with existing problems [4]. This scenario has contributed to the development of technological tools and maintenance programs, capable of detecting anomalies in the operation of systems, enabling the decision-making regarding the maintenance of equipment that increase the availability rate of the machines.

Therefore, this study aims to present a brief bibliographic review regarding the main ideas about the concepts of aeronautical maintenance, from the first fruits of preventive maintenance, that served as a basis for the development of techniques of predictive and detective maintenance. These tools can be applied to monitoring reliability over the life of an aircraft. The objective was also to present the possible benefits to operators encountered during the application of prediction and detection techniques to increase safety and reduce operating costs.

2. Maintenance

Despite the rare documentation on the subject, the maintenance always existed, even in the most remote ages of mankind. Reports on the subject began to receive more attention around the 16th century in Central Europe, due to which the invention of the mechanical watch came the imminent preparation of the first technicians in assembling and assisting in this equipment.

The mechanization of industry in the late XIX century required frequent maintenance routines. The intervention only occurred when the equipment lost its function. Corrective maintenance is also known to adopt the "Run To Failure" (RTF) philosophy, which means "operate until broken." At this stage, the tasks of equipment maintenance were based on simple repairs and its cleaning and lubrication activities of the machines.

In the early aviation days, maintenance programs were based on mechanical failures and they were simple. Operators did not develop an analytical base capable of providing data for future interventions. With the first airlines, specific requirements were created for the construction of aircraft and rules were implemented not only for flight activities but also to improve maintenance activities.

With the development of series production implemented by Ford and the need to increase production due to the first major war, factories felt the need to create teams subordinate to an operation and tasked with correcting failures and keeping active production lines the largest time. It is in this scenario that corrective maintenance arises, this situation remained stable until the 1930s, when, due to the Second World War, the demand for industrialized products experience a great expansive, presenting acceptable levels of quality and reliability [5].

In aviation, the industry formed a task force whose purpose was to investigate preventive maintenance capabilities. The result of this work was the creation of maintenance called "on-condition maintenance", or maintenance based on the airworthiness condition of the item, and it was overhauled or replaced at predetermined intervals. Haguma wrote the "Maintenance Evaluation and Program Development" manual or known by the acronym (MSG-1). It was developed in 1968 by the Air Transport Association (ATA) through a group of manufacturers of aviation industry structures, "Maintenance Steering Group" (MSG) [7]. The development of MSG-1 was based on development in maintenance scheduling and it was applied in the new Boeing 747.

In the 1970s, maintenance became the subject of scientific research, and in 1976 the integrated concept of maintenance and production was developed by the British M. Husband and Dennis Parkes from Life Cycle Cost (LCC) orientation [5]. Piechnicki [6] emphasizes that this set of practices involves financial management, specific technical and logistical planning, among others, applied to physical items in order to reduce the costs of their life limits cycles, was known as Terotechnology.

Following the development of aviation, the industry have developed the "MSG-2" [7], which has implemented the philosophy of the study of fault analysis, based on the theory that all aircraft and their components reach a stage where they must be completely revised to return to the factory out condition or "overhauled", where their condition is restored to the new condition.

In 1978, the United Airlines at the request of the aeronautical industry assembled a database that subsidized the design of new maintenance programs based on proven practices on the aircraft in operation. This new methodology was the basis for MSG-3, which was adopted as the standard by the aeronautical industry [7]. This methodology of preventative maintenance is guided by the analysis of the failures with the objective of feeding a robust database, making maintenance interventions carried out with a focus on operational safety and guided by the need to reduce operating costs.

According to Silva [8], in the 1980s and 1990s, the use of ever more efficient computers and software improved the processes of order generation, made possible an improvement in inventory control and logistic support, increasing planning preventive maintenance and providing important support for predictive maintenance. The idea was that through effective diagnostics and their respective prognoses, costs would be reduced and reliability increased.

For Zaions [5], the definition of contemporary maintenance encompasses the various types of maintenance that exist. This large range of definitions sometimes makes it difficult to characterize maintenance types. "Some basic practices define the main types of maintenance, which are: Unplanned Corrective Maintenance; Planned Corrective Maintenance; Preventive maintenance; Predictive/Detective Maintenance and Maintenance engineering" [5].

The need to strictly control the condition of each aircraft has meant that operators have improved maintenance techniques. While in the predictive maintenance, it is necessary the diagnosis from the measurement of parameters; The diagnosis is obtained directly from the processing of the information collected in the aircraft and in some cases transmitted in real time to monitoring stations.

Maintenance Engineering presented the concept of "Maintenance Diagonal", which encompasses a series of actions designed to align activities involving external agents such as suppliers and service providers among others, causing maintenance activity to become a strategy for the success of organizations.

3. Types of maintenance

Aircraft maintenance focuses on restoring the condition of a component in accordance with the parameters stipulated by the manufacturer. For Rodrigues [9] the maintenance of an aircraft is a set of specific operations that involve sometimes complex procedures, these activities must be performed by qualified personnel. According to Serrano [10], the process of aircraft maintenance consists in performing a flow of tasks to maintain the continued airworthiness of the aircraft in service.

According to Almeida [11], there are five basic maintenance techniques frequently used by aircraft operators, these types of maintenance are divided into two groups: Unscheduled Maintenance and Planned Maintenance. Planned maintenance will incorporate the techniques of prevention, prediction, and detection, while unscheduled maintenance takes the immediate need for correction and the opportunity to resolve non-compliance before it becomes a problem. This is occasional maintenance. Each type has specific characteristics, are applied according to the need of the activity and complexity of the equipment.

3.1 Unscheduled Maintenance

Unscheduled Maintenance can be defined as fault correction at random, such as emergency maintenance. This type of maintenance is applied when the fact has already occurred, whether it is a failure or poorer performance than expected.

According to Almeida [11], there is no time for preparation of the service. Generally, this type of maintenance means high costs, since the unexpected break can have several effects, such as production losses, quality losses, and high indirect maintenance costs.

3.2 Planned Maintenance

Planned Maintenance is intended to prevent or correct something from less than expected performance or failure. This maintenance can be divided into preventive, predictive and detective maintenance.

In preventive maintenance, the action is performed in order to reduce the possibility of failures or reduction of performance, through a plan that is based on defined intervals of time. Therefore preventive maintenance consists of a set of procedures and anticipated actions that aim to keep the machine in operation subsidized by a sequence of inspections followed, if necessary, by a sequence of corrective actions.

The use of preventive tools on the parts wear from experimental observations and operating statistics imposed on manufacturers a routine of anticipation of failures such as the adoption of replacement of components according to the number of cycles of work or operating time. In this case, the components are replaced on the basis of prior schedules stipulated during the execution of the aircraft design, fail-safe, safe life or Damage Tolerance.

This philosophy persisted for decades, and at that time many items of high monetary value were replaced and discarded based on performance projections pre-established by manufacturers. On several occasions, these components were removed before they actually were compromised or at other times failures occurred within the "useful life" of the component.

In aeronautical follow-up, the replacement of items is performed according to criteria pre-established by the manufacturer and all activity of the mechanics should be reported in the specific documentation. For Silva [8] preventive maintenance, constantly seeks to avoid failure, that is, to prevent. The author considers Preventive Maintenance as a set of programmed activities, usually repetitive, that allow to verify and maintain a certain level of functioning.

Detective maintenance works in protection systems with the objective of assisting in the early diagnosis of malfunctions that are hidden or not perceptible to operators and maintenance personnel. This type of maintenance was created from technological support provided by computers and increasingly reliable data processing and transmission systems that operate directly on aircraft. The introduction of preventive and detective maintenance techniques are presented as effective alternatives not only to reduce unwanted stopping levels by unscheduled maintenance but also by the possibility of anticipating parts requests to be replaced in scheduled maintenance.

4. Predictive maintenance techniques

Predictive maintenance, also known as maintenance technique based on the condition, evaluates the actual state of the equipment using specific resources and equipment in order to support preventive maintenance planning. This type of maintenance aims at early detection of possible equipment failures, thus avoiding the emergence of more complex problems, which helps to plan maintenance based on real data.

While fleet safety is paramount and requires diligent maintenance schedules, incorporating predictive analytics can streamline the maintenance operations dynamic and add the potential for improved profitability [1].

Predictive maintenance uses the real conditions of an equipment or system for its own optimization. Also, the predictive maintenance breaks with subjectivism, because it uses parameters and real monitoring data, which can be submitted to a careful, logical analysis and objective through an automated process thus reducing the likelihood of human error since this little interferes with the process. This information, when used to assess the condition of the equipment, provides support for corrective action if necessary.

The American certification agency, American Bureau of Shipping (ABS), has published Reliability Centered Maintenance (RCM), a model for fault analysis [12]. For the agency, the baptized curve (P-F), illustrates the final steps of a failure. The model shows the beginning of a point where failure begins, but the point represented by the letter P announces the point of the curve, where the degradation of the monitored item is enough to be detected (Onset of Failure). Then, if the discrepancy is not properly identified and corrected, the degradation process is continued until it reaches the point represented by the letter F which signifies the Functional Failure of the item. If a potential fault between points P and F is detected at on time, it may be possible to take measures to prevent the collapse of the item or at least to minimize the effects. Figure 1 shows the component degradation curve predicted in the model.

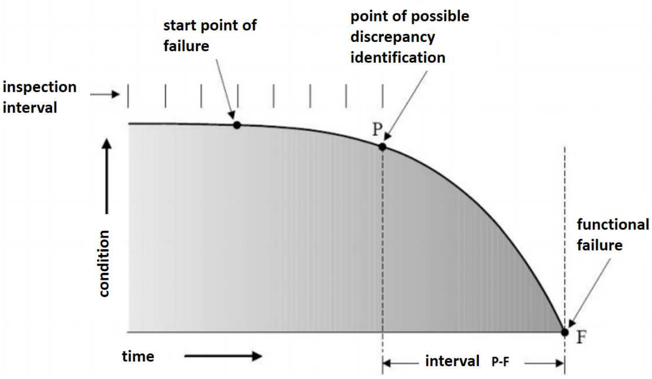

Fig.3: Diagram P-F. Guidance notes on reliability-centered maintenance ABS (2004).

For Silva Filho et al [13], "an Engineering System, like an airplane, can present itself in two crucial situations from the point of view of safety and reliability: with the presence or not of failures". The authors consider "failure" an abnormality in the functioning of the system, or even the inability of the system to perform the functions for which it was designed. In this way, a diagnostic system has three possible states: Normal (no failures), Degraded (partial failures or a portion of their functions) and Inoperative (totally failed). "

According to Silva Filho et al [13], the safe and anticipated reversal of an eventual "degraded" state to "Normal", before reaching the functional failure point F of the PF diagram, is the challenge and focus of this monitoring effort.

In order for the predictive maintenance routine and its concepts of monitoring the condition of the item, system or aircraft monitored and operating trends to be efficient, some aspects have to be considered by those responsible.

These are fundamental conditions for the use of predictive maintenance techniques:

• The item must allow the application of the technique when the component presents some indication of degradation that can accelerate its potential failure.

• Failures must come from causes that allow monitoring as well as the progression of degradation.

• The interval between Point of Identification P and Functional Fault F must be consistent so that the operator does not take early corrective actions.

• P-F intervals shall allow degradation of the item to be detected and corrective measures taken within the time interval delimited by the P and F points.

• Monitoring actions should be implemented to reduce the probability of failure to acceptable levels of safety.

• The maintenance team should be able to set limits that need corrective interventions.

• The item must be monitored according to its value, and the cost of executing the predictive techniques should not exceed the value of the item and or the total costs resulting from the consequences resulting from the possible failures.

Over the last few decades, the aeronautics industry has benefited from the various technologies developed to evaluate the state of the equipment. Among the most common tools we can highlight the following:

• Analysis of lubricants, in the search for: number of neutralization acidity or basicity, water content "insoluble verification", counting of metallic particles by spectrometry by Infrared Gas Chromatography, Interfacial Voltage, Dielectric Rigidity and Flash Point.
• Analysis of vibrations in mechanical and engine assemblies.
• Analysis of the condition of surfaces.
• Analysis of electric motors.
• Temperature analysis.
• Analysis of noise.
• Detection of leaks.
• Acoustic emission.
• Non-Destructive Testing (NDT).
• Flow measurements.
• Corrosion monitoring.
• Thermography.

Among the main objectives of the prediction is the maintenance action only when there is really the need of the intervention. This fact optimizes part replacement or component inspection and ultimately extends maintenance intervals by predicting when the monitored item is close to its useful life limit.

5 Detective maintenance techniques

Since it was mentioned in the aeronautical literature from the 90's, the detective maintenance arose from the need to improve the conditions of monitoring the health of the aircraft, which reflects in the improvement of the conditions inherent to flight safety, and it was driven by the policy of forecasting replacement of components always before their possible failures, under diagnostics and anticipated prognoses, increasing the level of reliability of the equipment.

Having its Detective name originating from the word "Detect", maintenance is a monitoring technique performed on systems that are working, whose purpose is to identify hidden or imperceptible faults to the operation and maintenance personnel. This technique allows experts to check the operating conditions of a given system without removing it from the operation. In some cases, in addition to detection, it is possible to correct discrepancies without interrupting the operation of the system, and it is not possible to continue the operation, those responsible for maintenance can opt for planned corrective maintenance, which presents a lower cost than the unplanned one.

In aircraft, the identification of hidden faults is paramount to guarantee reliability, this technique was already applied for several years, even when it did not respond by that name. Some equipment and systems when being put into operation, make the so-called "self-test", indicating the existence of some abnormality.

What evolved from predictive maintenance to detective maintenance was the evolution of the automation of the prediction systems, that is, in the maintenance of most of the information about the conditions of the monitored item, are transmitted in real time to an analysis platform that allows the corrective action immediately.

6. Predictive nowadays

The technological evolution achieved in recent decades has allowed the aeronautical industry to implement new communication technologies between aircraft and ground stations. Created in 1978 by the company Aeronautical Radio Incorporated, (ARINC), the Aircraft Communications Addressing and Reporting System, (ACARS), allows the exchange of information between aircraft and earth stations. Among the data transmitted, we can highlight the packages related to the health of the machine and its systems [14].

From this technology, companies like Airbus and Boeing have developed data collection and processing platforms capable of monitoring the performance of all aircraft operating on the planet. Airplane Health Management (AHM), developed by Boeing [15] in one of its modules, allows the operator to receive real-time information on the fuel consumption and the amount of carbon dioxide (CO_2) emitted by the aircraft, allowing airlines to optimize the operation of an aircraft or of entire fleets.

AHM technology allows the operator to access a series of data from his aircraft through a web portal developed and managed by the company with "MyBoeingFleet.com". Real-time information not only serves to diagnose possible failures in progress but also helps in making decisions about whether or not immediate intervention is needed or the scheduling of a stop not previously planned in a timely manner.

The package marketed by Boeing also counts on the performance monitoring module and more two monitoring modules that can be accessed by the operator related to performance and fault diagnosis. (Real-Time Fault Management and Service Monitoring).

The next-generation technological apparatus on board aircraft such as the Boeing 787 and Airbus A 380 enables technology companies such as Inmarsat [16] to use a series of satellites to monitor the health of machines by passing on this information in real time to specialized teams in the land. Electronically verified checks result in immediate and reliable diagnostics, allowing maintenance teams to prepare to take corrective action as soon as the aircraft lands.

7. Examples of programs

At the beginning of the 21st century, a North American company offers the market a predictive maintenance program, based on the analysis of the conditions of the engines in operation. Named "Maintenance On Reliable

Engines" (MORE) Program, this program became known worldwide as the M.O.R.E. program [17].

A differential proposed by the MORE program is to increase the time between overhaul (TBO), from the average time 3600 hours of operation for the motors of the family of motors PT6A, to 8000 hours. The engine operating cost using the MORE Instructions is usually less than one half the cost of a typical engine overhaul [17].

The program uses a number of tools to diagnose failures, among them are the engine vibrations analysis, which makes it possible to verify the integrity of the rotating assemblies of the engine; The "Spectrometric Oil Analysis Program" (SOAP). The tests are performed on sophisticated equipment, where from the obtained results, information is provided in advance on the state of the internal components of the motors, quickly predicting the possible faults. The spectrometric analysis is characterized not only by the analysis of oils but also by an orientation on the measures to be taken, permanent technical assistance and mainly by the management of the database of each engine, specifically, each module, resulting in the increase useful life by detecting and preventing specific cases.

This type of analysis, limited resources and time invested in the predictive maintenance of the engine and allows the operator to prevent failures and increase the margin of safety of their operations.

The proposed engine monitoring solution during its operation is to detect and find possible engine failure points before they become serious, dangerous and costly to the operator, so the MORE program has become an option for the various operators spread throughout the world.

The British Rolls Royce, [18], uses detection techniques to monitor the health of their gas turbines. The Engine Health Management (EHM) system, applied to Trent family motors, monitors through 25 sensor data from the engines that are shipped via satellite to the manufacturer, the health conditions of all engines operating in the world.

For Rolls Royce, the development of the EHM system has contributed to a significant reduction in the costs of detecting potentially costly technical problems. For the operators, the use of the data, help in the development of maintenance programs more efficient, economic and reliable [18].

The Airbus's Aircraft Maintenance Analysis [19], used by more than 100 customers, constantly monitors health and transmits faults or warning messages to ground control, providing rapid access to maintenance documents and troubleshooting steps prioritized by the likelihood of success. Meanwhile, Boeing's Airplane Health Management (AHM) is used on 2000 aircraft for 53 customers nowadays.

Since 2016 the Airbus [20] company are moving more and more towards predictive maintenance and automated inspections to reduce the burden of inventory costs and lead times. With the Industry 4.0 revolution, it became clear to Airbus that that achieving true end-to-end digital continuity for the entire lifecycle of an aircraft meant extending digital technologies and principles to maintenance activities. Airbus aims to reboot the MRO sector with its Hangar of the Future, an innovative application of state-of-the-art technologies and methods aimed at increasing operational efficiency for customers' aircraft worldwide. [20]

More data equals better answers, faster. The growing volume of data company predictive maintenance solution collects will have even broader applications going forward. The company will likely be able to exploit new ways to achieve operating cost reductions as their acquire more data about their personnel, processes and equipment [1].

Equipment data can be equally useful for analytics. While onboard sensors, visual inspections and the work done during overhaul provide a wealth of information, adding an analytics software solution with cognitive learning capability can allow you to extract new insights from that data to lead to additional benefits. For example, the solution may reveal that washing landing gear before maintenance can improve productivity [1].

The detection of abnormalities prematurely is a differential for the operators, because it facilitates the immediate provision of spare parts, allows to plan the anticipated displacement of trained technicians what results in the reduction of the time of stop of the aircraft in function of a maintenance activity not programmed.

5 Final considerations

From the documentary research the prediction of the aircraft maintenance was contextualized, as well as the main types of maintenance applied in aircraft were described. It is a fact that the maintenance of aeronautical products has been evolving with the introduction of increasingly clear techniques for the detection of nonconformities, which require a better management of the repair processes of aircraft and aeronautical products.

The XXI century requires the airlines, suppliers and other stakeholders to implement measures that can reduce operating costs, increase the availability of aircraft for operation, and extend their useful life limits under the pre-established safety conditions of the agencies regulating civil aviation. For aviation companies, delays and cancellations are a huge and expensive problem. Up to 30% of the total delay time is due to unplanned maintenance. This predictive maintenance approach can also help improve areas such as supply chain optimization, inventory allocation and planning, aircraft reliability improvement and operation and schedule planning.

It was verified that aircraft maintenance models, based on prediction and detection, are fundamental tools for the achievement of mentioned objectives and that the maintenance of contemporary aircraft has to stop being just efficient and effective, aiding in the battle of competitiveness by the various airlines and small operators.

The second paradigm break-in maintenance, implemented by aeronautical maintenance engineering, predicts that the operator must stop being constantly repairing but identifying the origins of the failures, and attack them, modifying the unsatisfactory performance situations, correcting chronic problems.

It is concluded, therefore, that the management of aeronautical maintenance should align as soon as possible with the modern and efficient techniques of predictive and detective maintenance. The realistic diagnoses about the aircraft operating conditions allow those responsible for the construction and maintenance to draw normal operating profiles so that eventual malfunctions and degradation processes are detected with anticipation of possible failures. Moreover, the techniques of detection and prediction can help in the reverse direction of degradation diagnoses, being able to ensure that components and high-cost parts that still have full conditions for use are discarded prematurely based only on recommendations of a preventive nature and statistical, imposed by the maintenance policies implemented in the twentieth century. Experts estimate such approaches can increase aircraft availability by up to 35%. However, unlocking the secrets of big data in commercial aviation is still to be tackled.

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