# Development and Application of Maintenance Strategy for Commercial Aircraft

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***Abstract*—Maintenance strategy is developing with the improvement of industrial technology. The application of advanced maintenance strategy is particularly important for high-value products such as commercial aircraft. This paper introduces the classification of maintenance strategies, and describes the application and development of preventive maintenance and condition-based maintenance for commercial aircraft.**

***Keywords-preventive maintenance; predictive maintenance; condition-based maintenance***

## I. INTRODUCTION

Maintenance is a broad domain and plays an important role in modern industries. Insufficient maintenance or improper maintenance can cause unexpected consequences or even lead to serious consequences and accidents. In the past several decades, maintenance strategies and methods have been developed with the aim of carrying out maintenance tasks more effectively [1].

Commercial aircraft is a typical complex high-end product. Compared with most other industrial systems, commercial aircraft is an extremely complex system engineering. Maintenance strategy is the focus of aircraft manufacturers. Modern air transport requires commercial aircraft to have high utilization rate, high mission reliability and low operation cost. Therefore, commercial aircraft is required to adopt the most advanced maintenance strategy to determine the optimal maintenance time and task, so as to reduce the down time caused by unexcepted failure and improve the availability of the aircraft.

## II. MAINTENANCE CATEGORIES

As can be seen from Fig. 1, maintenance can be divided into two categories: reactive maintenance and proactive maintenance. Proactive maintenance can be further classified into two types: preventive maintenance and predictive maintenance [1][2].

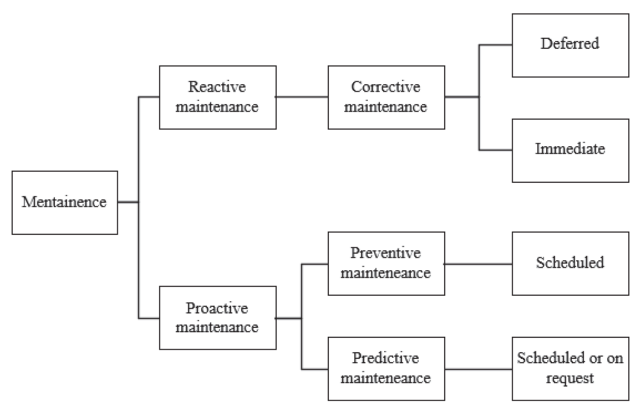


Figure 1. Maintenance types [1][2][3].

Reactive maintenance, namely corrective maintenance, is unscheduled. Corrective maintenance is breakdown maintenance. It applies to simple equipment or components that do not affect safety and cause failure consequences [2]. Various devices, such as household appliances and mobile phones, usually adopt corrective maintenance. Normally, the run-to-failure of these devices does not cause serious influence and can be repaired or replaced quickly. Therefore, it is more reasonable to repair run-to-failures rather than prevent them [1].

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However, there are various issues and weaknesses in most complex industrial systems. For example, many functional failures of commercial aircraft are directly related to safety. It is impossible to adopt corrective maintenance after the failures occur. Therefore, proactive maintenance is required for complex industrial fields, such as aircraft, ships, automotive and large industrial equipment. CBM (Condition-Based Maintenance) is an effective maintenance strategy widely used in commercial aircraft. Fig. 2 shows the relationship between failure rate and maintenance strategy evolution.

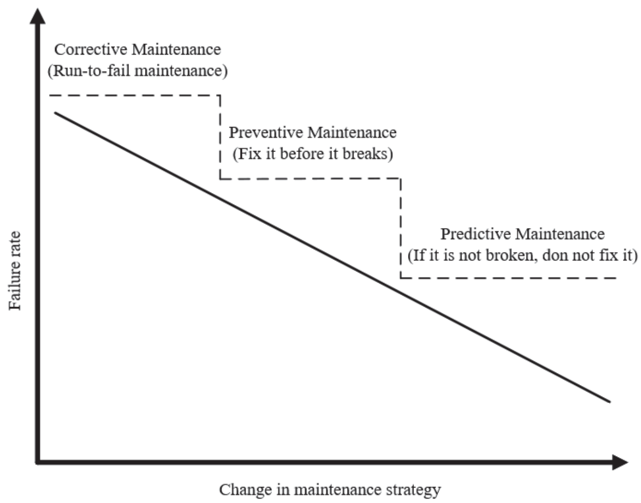


Figure 2. Change in maintenance philosophy [4].

Table I is a comparison of different maintenance strategies. Compared with corrective maintenance and preventive maintenance, predictive maintenance has remarkable advantages and is more suitable for modern complex systems. Therefore, predictive maintenance is a more promising maintenance strategy in the future.

TABLE I. COMPARISON OF DIFFERENT MAINTENANCE STRATEGIES [4]

| | Advantages | Disadvantages |
|---|---|---|
| Corrective maintenance | 1) Avoid being over-maintained<br>2) No condition monitoring related cost | 1) High downtime<br>2) High cost of spare parts and logistics<br>3) High safety risk |
| Preventive maintenance | 1) Reduce the probability of serious functional failure<br>2) Better maintenance plan<br>3) Better management of spare parts | 1) Waste of remaining useful life<br>2) Maintenance is performed prematurely |
| Predictive maintenance | 1) Reduce unexpected breakdown<br>2) Optimize management of spare parts<br>3) Prolong the servicing life of the equipment | 1) High initial investment cost<br>2) High technical requirements |

## III. PREVENTIVE MAINTENANCE OF COMMERCIAL AIRCRAFT

The most typical example of preventive maintenance is MRBR (Maintenance Review Board Report) which is commonly known as a maintenance program. It is an essential document required by the aviation authority (EASA/FAA) for the continued airworthiness of commercial aircraft. Maintenance program establishes initial scheduled maintenance tasks and intervals for aircraft and outlines the initial minimum scheduled maintenance and inspection requirements of all aircraft systems and structures. It aims to maintain the inherent safety and reliability of the whole aircraft lifetime [5].

The maintenance or inspection requirements is formed by MSG-3 procedures and listed in the MRBR [5]. “ATA MSG-3 Operator/Manufacturer maintenance program Development” is used to produce the civil aircraft maintenance program. MSG-3 logic is a method to produce preventive maintenance based on engineer experience. Certainly, this experience-based approach also requires a combination of a lot of specific design and experimental data. The MSG-3 document illustrates the principle and procedures for forming the scheduled maintenance task and interval [5]. MSG-3 logic is a method of Reliability-Centred Maintenance (RCM). After tasks have been determined through the MSG-3 process, their related task intervals will be determined based on MTBF (Mean Time Between Failures), MTBUR (Mean Time Between Unscheduled Removals), experimental data, design character operational experience, engineering judgments, and related data of other reference aircraft. The following aspects below are taken into account when determining the task interval.

- Experiments and analysis report of suppliers and manufacturers.
- Data and recommendations from suppliers and Manufacturers.
- Requirements of the operators.
- Service and operational experience from identical or similar systems and components.

Manufactures and airlines have shown that it is an effective way to develop an efficient maintenance program by using the MSG-3 logic for commercial aircraft from the past operational experience [5]. The suggested intervals may base on the letter check, and the task interval is specified as one of FH (Flight Hour), FC (Flight Cycle) and/or calendar time, which is sensitive to the task.

As mentioned in the previous section, commercial aircraft currently rely mainly on preventive maintenance to ensure the continued airworthiness and operation of the aircraft, such as the preventive maintenance intervals and requirements of fuel filters in the maintenance program. Many systems of aircraft require various filters, such as oil filters, fuel filters, and air filters. The preventive inspection interval of the fuel filter for the Boeing 777 aircraft is 2000 FH [6][7]. Table II shows the fuel filter inspection or replacement intervals of Boeing aircraft. There are the official recommendations for scheduled maintenance of fuel filters on a regular basis in the maintenance program of Boeing aircraft. Inspections or preventive maintenance requirements of all important components or items are provided in the maintenance program. Specific maintenance operation can infer to AMM (Aircraft Maintenance Manual).

TABLE II. FUEL FILTER MAINTENANCE RECOMMENDATIONS OF BOEING AIRCRAFT [7]

| Aeroplane Model | Recommended Maintenance Interval of Fuel Filter | Task Type |
|---|---|---|
| 737 CL | 1C check | Check |
| 737 NG | 6,000 FH | Fuel filter replacement |
| 747-400 | 7,500 FH or 18 months (whichever comes first) | |
| 757 | 3,000 FH | |
| 767 | 3,000 FH | |
| 777 | 2,000 FH | |

Different aircraft have different inspection or replacement requirements. For modern commercial aircraft, inspection, cleaning or replacement of fuel filter are based on a regular basis. The fixed interval is derived from the MSG-3 logic used in the civil aviation industry. Inspection of the fuel filter is performed during the C check. The fuel filter replacement interval of 737 NG is at 6,000 FH. The fuel filter replacement interval of 747-400 is at 7,500 FH or 18 months (whichever comes first). For 757 and 767, it is necessary to replace the fuel filters at 3,000 FH. The inspection interval of 777 fuel filter is at 2,000 FH [7]. Nowadays, almost all the commercial aircraft utilize the scheduled maintenance to ensure the safety and airworthiness.

## IV. CONDITION-BASED MAINTENANCE (CBM)

Predictive maintenance can predict reasonable maintenance time points based on the real-time situation of equipment [4]. Predictive maintenance is used to determine needed maintenance task and related interval according to the actual condition of equipment [4]. The real-time parameter data is obtained from BITE, embedded sensors or external detection devices. CBM is a maintenance method which has been widely concerned in recent years. This type of predictive maintenance is performed when indicators show that there is going to have a failure or the performance is deteriorating. Appropriate maintenance always can be carried out at the most proper time with CBM technique [4]. It can be obtained from the comparison in Fig. 3 that the maintenance timing and process are optimized after applying prognostics technology and achieving condition-based maintenance.

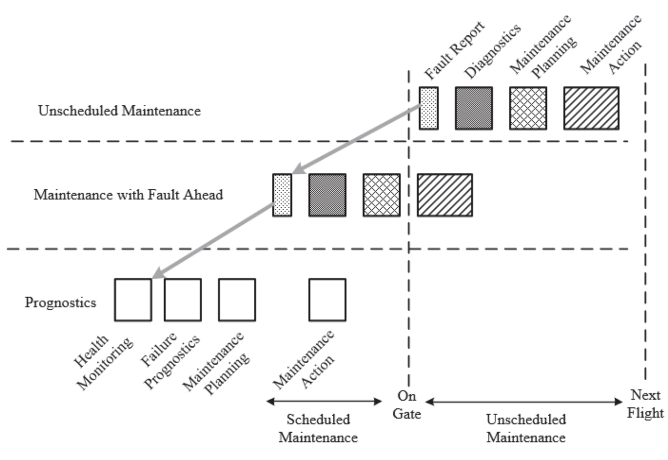


Figure 3. Improvement of CBM.

The objectives of an efficient CBM are as follows.

- To maintain inherent equipment level of safety and availability.
- To restore the inherent level of safety and reliability when performance has deteriorated.
- To find the weakness or design defects of equipment and obtain the information necessary for design improvement.
- To accomplish these goals economically [5].

CBM allocates and optimises maintenance resources based on real-time monitoring data and state parameters analysis. CBM is a promising technology and can take the place of traditional inspection or replacement intervals on a regular basis.

There are the following advantages of CBM:

- To minimise the required maintenance.
- To minimise spare parts cost and.
- To reduce maintenance personnel.
- To reduce maintenance time.
- To shorten system downtime.
- To increase the operational aircraft availability.

CBM can greatly improve the availability of aircraft. Availability is a vital aspect of product competitiveness. It is necessary to apply an effective maintenance strategy to improve product availability and utilization [4]. CBM is promising predictive maintenance that can avoid the consequences caused by functional failures. It will replace traditional corrective maintenance and pre-determined maintenance gradually.

### *A. P-F Interval*

CBM is different from corrective maintenance and predetermined maintenance because its maintenance task is based on the expected P-F interval [4]. P-F Interval is the interval between the point at which a potential failure becomes detectable and the point at which it degrades into a functional failure [4]. Most failure modes have some signs of deterioration in performance or failure to occur. It is possible to detect the clues of degradation at the early stage of failure. A typical P-F interval curve is illustrated in Fig. 4. P-F interval is required to be long enough to adopt appropriate maintenance activities [11]. The maintenance plan and maintenance preparations can be completed when the systems are running. This part of the preparation and reaction time can bring great benefits to system operation [8].

The task intervals of CBM is mainly depended on the expected P-F interval. Therefore, the P-F interval determines the maintenance interval and frequency [4]. To ensure to detect potential failures before functional failures are formed, condition monitoring is required to be continuous or the monitoring interval is less than the P-F interval [4].

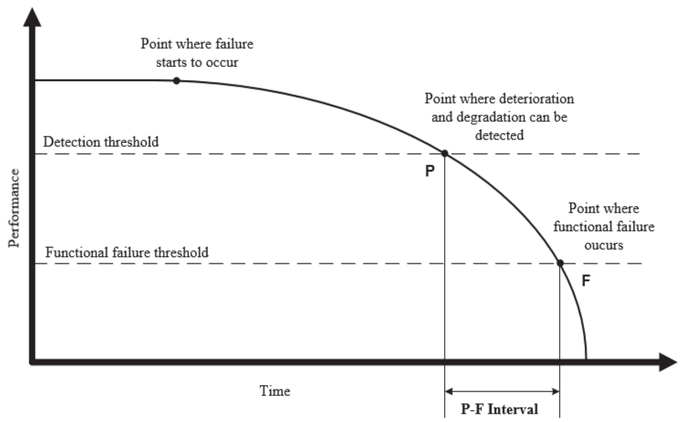


Figure 4. P-F interval curve [2][4].

### B. OSA-CBM

Diagnostics and prognostics are two important aspects of realising condition-based maintenance. Fig. 5 illustrates fault-to-failure progression timeline that can show the different processes of prognostics and diagnostics. The timeline shows the process from an incipient fault to failure and reveals the relationship between prognostics and diagnostics [9]. More advanced diagnostic techniques can detect fault symptoms earlier. The length from very early incipient fault to the failure is the prediction range.

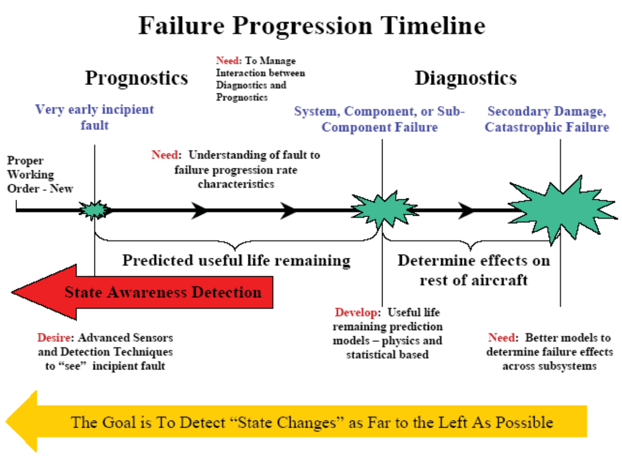


Figure 5. Failure progression timeline [9].

Open System Architecture for Condition-Based Maintenance (OSA-CBM) aims to define and develop open standards for distributed CBM and define an open architecture not exclusive to any specific hardware implementations, OSs, or software technology. OSA-CBM is an implementation of ISO 13374 standard for condition monitoring and diagnostics of machines - data processing, communication and presentation. Fig. 6 shows the OSA-CBM architecture which must comply with the ISO 13374 standard.

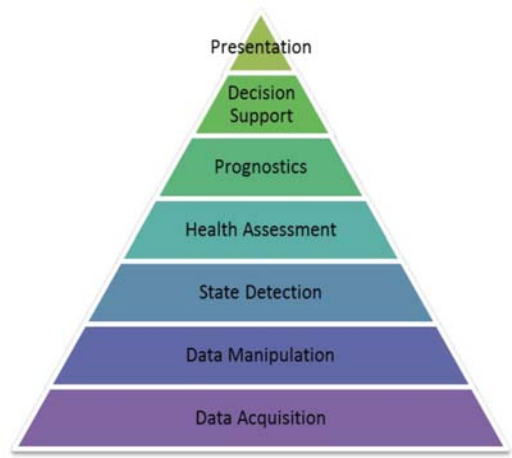


Figure 6. The OSA-CBM architecture [2].

Condition monitoring data are required to be processed and analysed by relevant data processing and analysis procedures [10]. Fig. 7 illustrates the data processing and information flow which can be divided into six layers of function blocks. The lower three levels give out low-level, application specific functions and the next upper three levels present decision support to maintenance and operation according to the health condition of the target systems.

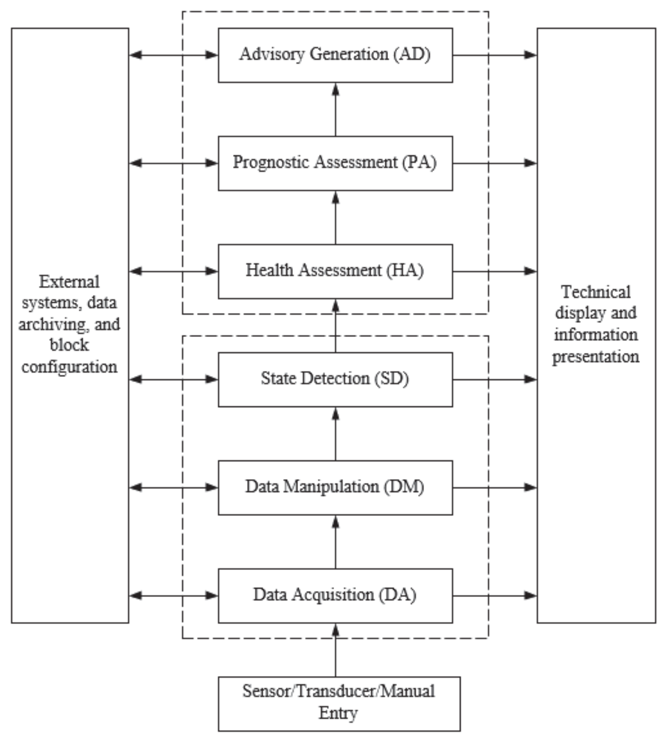


Figure 7. Data processing and information flow blocks [10].

Data and information flow starts from the bottom and generates results adopted by the maintainer or operating personnel at the top layer [10]. The data and information flow are transmitted from the former layer to the next layer. In this progress, additional information is required to be input and output with an external system. Technical displays and information presentation are needed to be formed in this process [10]. The function of each layer of the whole progress is as follows.

- Data acquisition: to convert sensor output digital data.
- Data manipulation: to implement low-level signal processing.
- State detection: to support modelling of normal operation and detection of operational abnormalities.
- Health assessment: to provide failure diagnostics and health state assessment.
- Prognostic assessment: to forecast health state based on monitored data and usage loads and compute Remaining Useful Life (RUL).
- Advisory generation: to provide maintenance suggestion according to the systems' health condition.

## V. CONCLUSIONS

A brief introduction of maintenance strategies is introduced in the paper. The advantages and disadvantages of various maintenance strategies are compared. Also, taking the scheduled maintenance task of fuel filter as an example, the application of preventive maintenance for commercial aircraft is discussed. After that, the advantages of predictive maintenance and its operation principle are introduced. Preventive maintenance is a common maintenance strategy for commercial aircraft, which guarantees the safety and operational economy of aircraft in the past decades. However, there are also some problems, such as unreasonable scheduled maintenance intervals, which lead to waste of RUL of components. Predictive maintenance is the development trend of large complex and important systems. In recent years, the development of prognostic technology has brought opportunities for predictive maintenance. Condition-based maintenance is the result of the application of IVHM (Integrated Vehicle Health Management) technology in commercial aircraft. The application of IVHM technology has been considered to the greatest extent by newly developed commercial aircraft. Commercial aircraft manufacturers and operators are looking forward to the application of condition-based maintenance in a wider range to improve the availability, operational economy and competitiveness of aircraft.

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