# Reliability, Availability & Maintainability Analysis of A Aircraft and Spares

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*Abstract*:- **This paper presents a case study of an airline facing a challenge of increasing maintenance and reliability. The main purpose of this work is to develop a methodology that will, facilitate improvement of the logistic function of spare part handling, analyze the existing source of information that has been collected from authentic source. Additionally, this study is about prominent areas such as aircraft maintenance planning, availability and reliability.**

*Keywords* :- *Failure Free Operating Period, Failure Mode and Effect Analysis, Mean Down Time, Maintenance Free Operating Period, Mean Logistic Delay Time, Maintenance ,Mean Time Between Critical Failure, Mean Time Between Failure, Mean Time Between Maintenance, Mean Time Between Overhaul, Mean Time Between Unscheduled Removal, Mean Time To Failure, Mean Time To Repair.*

## 1. INTRODUCTION

An International Air Transport Association survey estimates that 36–40 percent of damage to aircraft is from ramp and maintenance damage, sometimes called friendly foreign object damage (IATA, 1991)

Maintaining a repairable system can be a complex task from economical and reliability point of view. High reliability is most essential which may not be connected with high costs. Due to the multidisciplinary characteristic of maintenance which consists of management planning, equipment, facilities, inventory and human resources, it is hard to overview and manage the maintenance tasks.

If a system is not maintained correctly, it will sooner or later cease to perform its required function with loss of safety and availability, besides reliability which will lead to several losses like economical, structural and in the worst case fatal injuries to humans. Within the aviation industry, the operational requirements are high and because of the consequences of failure, the maintenance procedures governed by strict legislation under strict directive from regulating authority. These directives are developed in a structured way of national requirements like international safety standards.

 The scheduled maintenance of an aircraft contains hundreds of timely/cyclic based inspections and replacements of parts. These can be divided into about 40, or more, groups with different periodic intervals, which are developed from maintenance strategy like MSG3.

Even if a system is maintained, deviations will occur, these deviations must be considered separately since they have a tendency to occur randomly at times and these are the unscheduled maintenance tasks. All implemented maintenance tasks, scheduled as well as unscheduled, must be recorded and archived.
For small and medium companies, it seems like this information is rarely used to improve the organization. Even if there are already developed software's available on the market, which takes care of probability calculations of failures and spare part optimization, the burden of license fees is too high for the small and medium maintenance organizations to justify the use of these.

Savings can be made by using the knowledge of previous maintenance data, although the use of an adopted software would be more effective, a simpler and cheaper analytic method can improve the logistic tasks like maintenance planning, spares, etc, and will also affect positively on aircraft availability and unpredicted expenses.

## 2. LITERATURE REVIEW :
There are various method to analyze the performance of system using RAMS.RAMS is a logistic tool that estimate the performance of equipment at different levels. It directs safety and operation problems and find the area in the system where refinement work should be done. Certain key performance parameters such as Mean Time To Failure (MTTF), Mean Time Between Failure (MTBF), Mean Down Time (MDT), Mean Time To Repair (MTTR) and Availability (A) values can be

determined to perform the analysis. The result gained from the statistics analysis of these values help in the assessment of the RAMS need of systems.

A. Discrete Analysis

MTBF = Total System Operating Hours / Number of Failures

MTTR = Forced outage hour / Total number of failure

Availability = System Uptime / System Uptime + System Downtime

B. Continuous Analysis

**2.1Reliability**

Reliability is the ability of the item to maintain the required function for a specified period of time under given operating conditions. Reliability function R(t) is defined as the probability that the system will not fail during the stated period of time t, under stated operating conditions.

Applications of the reliability function: R(t) is the probability that an individual item survives up to time t, R(t) is the fraction of items in a population that survives up to time t and R(t) is the basic function used for many reliability measures and system reliability prediction.

**2.1.1 Reliability measurements**

Broadly the reliability metrics are classified as:
 1. Basic Reliability Measures,
 2.Mission Reliability Measures,
3. Operational Reliability Measures and
4. Contractual Reliability Measures.

**Basic Reliability Measures** are used to predict system's ability to operate without maintenance and logistic support. Reliability measures like reliability function and failure function fall under this category.

**Mission Reliability Measures** are used to predict systems ability to complete mission. Reliability measures such as mission reliability, Maintenance Free Operating Period (MFOP), Failure Free Operating Period (FFOP), and hazard function fall under this category.

**Operational Reliability Measures** are used to predict the performance of the system when operated in a planned environment including the combined effect of design, quality, environment, maintenance, support policy, etc. Measures such as Mean Time Between Maintenance (MTBM), Mean Time Between Overhaul (MTBO), Maintenance Free Operating Period (MFOP), Mean Time Between Critical Failure (MTBCF) and Mean Time Between Unscheduled Removal (MTBUR) fall under this category.

**Contractual Reliability Measur**e is used to define measure and evaluate the manufacturers program. Contractual reliability is calculated by considering design and manufacturing characteristics. Basically it is the inherent reliability characteristic.

Measures such as Mean Time To Failure (MTTF), Mean Time Between Failure (MTBF) and Failure rate fall under this category.

**Availability**

Availability represents the probability that the system is capable of conducting its required function when it is called upon given that it is not failed or undergoing a repair action. Therefore, not only is availability a function of reliability, but it is also a function of maintainability.

**Availability Classifications:-**

* Point (instantaneous) availability
* Average up-time availability (mean availability)
* Steady state availability
* Operational availability

**Maintenance**

Maintenance and maintainability has always been important to the industry as it affects the performance as well as the finance. For commercial airlines, maintenance costs are approximately 10% of the airlines total costs. Operators would like their systems to be functional and available for safe operation when ever required. To achieve this there are in fact several ways to go, one of

them is to construct systems that are extremely reliable which consequently will result in higher acquisition cost,another way is to design systems that are easy and quick to repair when they fail, or some combination of these two described methods would do. Maintenance is a necessary action to sustain and restore the performance, reliability and safety of the item.

The definition of maintenance can be described as:
"*The combination of all technical and administrative actions, including supervision
actions, intended to remain an item in, or restore it to, a state in which it can perform
a required function*". (*BS 4778, 1991*)

## Maintainability measurements
The maintainability measure can be represented using the probability that the maintenance task will be completed by a stated time. Since the time used for maintenance is a random variable one can use the cumulative distribution function of the elapsed time to find the percentage of maintenance task that will be completed within a specific time
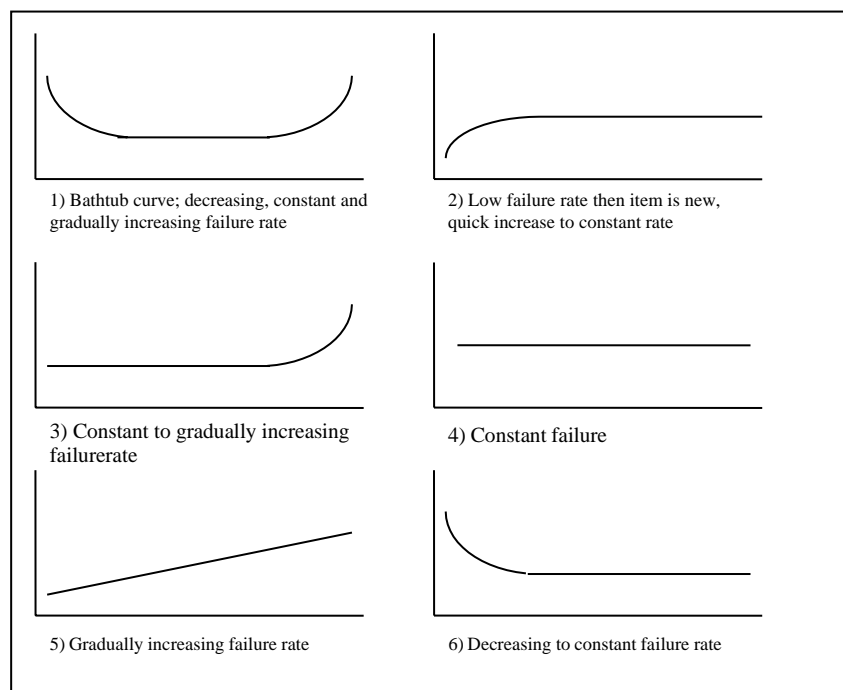
## METHODOLOGY
### Reliability Centered Maintenance
Reliability Centered Maintenance, (RCM), has its roots in the aviation industry in the late 1960s in conjunction with the introduction of the Boeing 747.

The maintenancerequirements from the Federal Aviation Administration resulted in a maintenance plan on which maintenance tasks were so extensive that the airlines probably would not have been able to operate the 747 with profit. As a result, the Federal Aviation Authority formed a Maintenance Steering Group, (MSG), consisting operator, manufacturer and regulator.
They researched the maintenance area of particular importance to various systems, so that a logical and generally applicable approachcould be used for developing maintenance strategies that could ensure maximum safety and reliability with minimization of cost. Further on, this resulted in MSG-2 and finally in the 1980s in MSG-3.

The RCM study has established that there where six failure related patterns, the most common failure pattern show a failure rate decreasing with age before going into a period of random failure pattern, and most uncommon pattern show a failure rate which is constant with age before going into a period of increasing failure rate. See all six kinds of patterns established in Figure



1) Bathtub curve; decreasing, constant and gradually increasing failure rate

2) Low failure rate then item is new, quick increase to constant rate

3) Constant to gradually increasing failurerate

4) Constant failure

5) Gradually increasing failure rate

6) Decreasing to constant failure rate

**RCM Process**

The process is used to identify system functions, the way these functions fail and the consequences of the failures and apply this information to develop an appropriate maintenance tasks to prevent system failures. Primarily, one can say that the objective of RCM is to preserve systems functions taking into account objectives as minimizing costs, safety and environmental goals, and finally meeting operational goals. Additionally objectives of RCM can be described as follows:

- To eliminate ineffective preventive maintenance tasks
- To focus maintenance effort on failures that may affect health, safety, environment, economic, operation and any other business related consequences
- To increase system availability
- To ensure system achieves inherent level of reliability
- To achieve the above mentioned goals at minimum operation, maintenanceand support costs
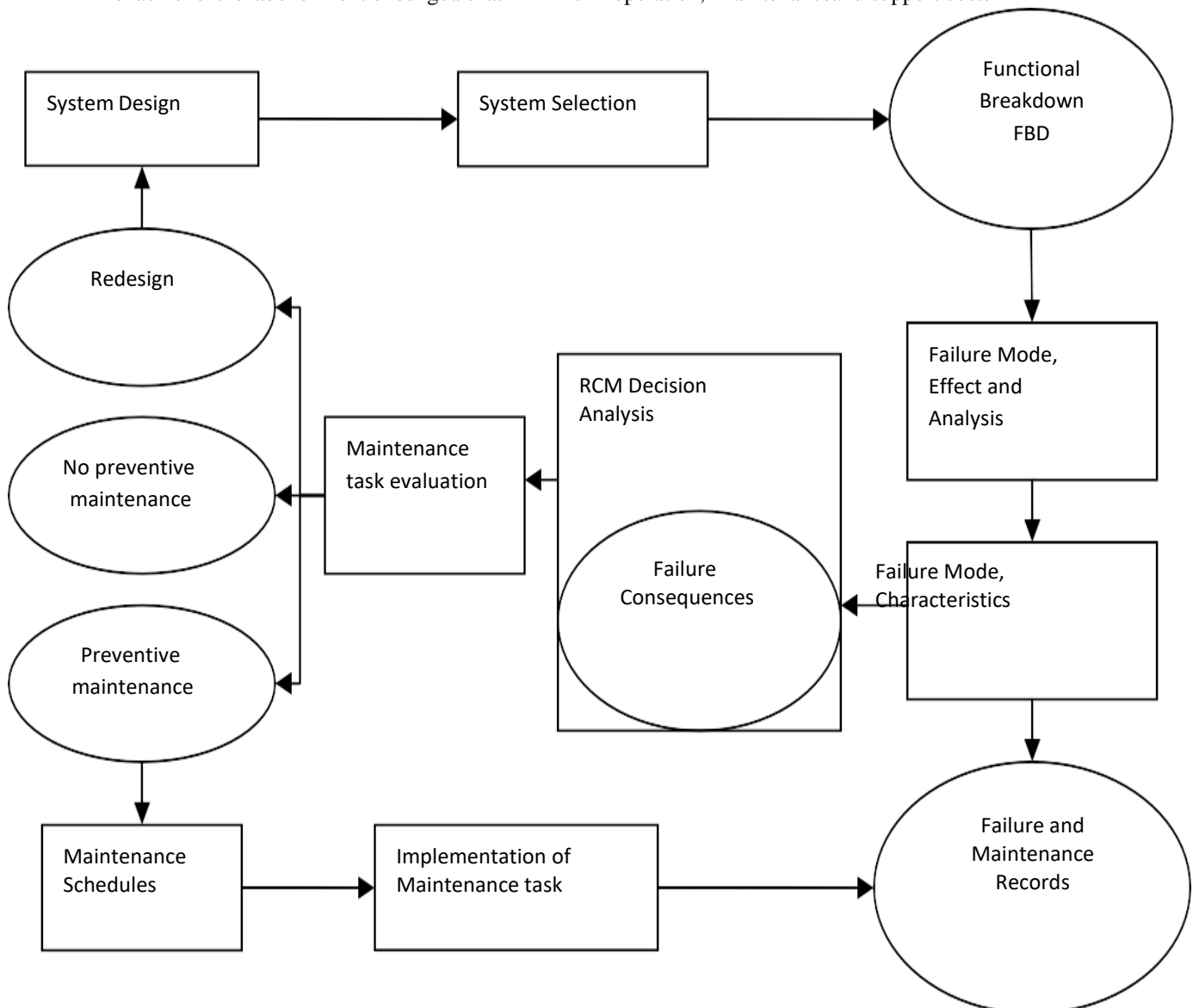


**Aircraft Maintenance Program (AMP)**

The AMP is based on several publications and documents, such as, aircraft- and engine manufacturer maintenance manual, airplane flight manual, parts catalogs, service bulletins, airworthiness directives and other state authority regulations. A list of the latest revision must be kept by the operators´ technical department. The operator is responsible for the technical

documents. The maintenance program inspection intervals can be expressed either in flight time as well as in calendar time and/or cycles.

The AMP is often structured in different chapters and related sub- chapters. First there is a section which consists of different lists and contents and further, there is a General section containing contents of, Applicability, Cross- references, Permitted variations and Airworthiness directives, etc. This is followed by the Maintenance procedures section, which in detail describes what to do, whether it is a special/periodic inspection or an overhaul. These detailed inspections are themselves divided into ATA-100 sub-group numbers.

### Sample aircraft fleet

Since the remarks/defects data from aviation operators commonly is confidential, it is hard to receive data for this study, this is due to its security and the competitivemarket with few actors. Although, some data has been provided, covering different aircraft types and sizes, and to protect the sources of these, we choose to use three unspecified sample aircrafts which represents the mean average of these data. These three aircrafts does also represent 10% of a minor to medium average fleet. The aircrafts are:

- Aircraft s/n 5 with initially 33350 runtime hours i.e. an aircraft near the end ofits life time cycle.
- Aircraft s/n 17 with initially 18620 runtime hours i.e. an aircraft in the middleof its life time cycle.
- Aircraft s/n 29 with initially 2130 runtime hours i.e. an aircraft in thebeginning of its life time cycle.

To be reasonable we assume that an aircraft in this average fleet flies 5 hours a day 6 days a week i.e. 1560 hours a year. Further on we assume that 1 flying hour equals 1 cycle which is a reasonable assumption for domestic flights. 1 cycle equals one takeoff and landing i.e. one flight, notice, this is only valid for short distance flights.

### Determine the scheduled maintenance

All scheduled maintenance tasks in the AMP were studied, inspections and replacements, based on cycles, and monthly intervals, were translated into run time hours based on the assumptions made earlier in chapter 4.2 above. The tasks were divided into three groups; "scheduled inspections", "special inspections/hard time components" and "overhaul and life limits". All tasks in each group which shall be performed at the same timely interval is indexed together to minimize the amount of data, *see Appendix I*. A study of the initial status of the aircrafts was done to determine what tasks have been done until the beginning of the timeframe, and when previously were done. We do assume that all aircrafts has been operated under the same AMP conditions since they first entered into operation. Further on, we determined what tasks should be done, and when, within the timeframe.

### Determine the unscheduled maintenance

Only five of the most frequent ATA groups will be undertaken in this study to represent the defects on the sample fleet. From the data provided, an average rate of the probability is determined in percentage on how likely it is, that an item fails (in respect of time limits for this study we regarding each group as one item) during one flying our.

**The result of this study gives the following probability:**

| ATA | Description | Probability to fail/flight hour (%) |
|-----|-------------|-------------------------------------|
| 25 | Equipment/Furnishings | 1,67 |
| 32 | Landing gear | 0,83 |
| 72 | Engine | 0,3 |
| 76 | Engine controls | 0,27 |
| 79 | Oil | 0,56 |

Table 4.1 The probability to fail for each ATA group

When the probability of failure per flight hour is determined for each ATA group, we can determine the defects spread over the year, by randomize a number between 1-100 for each run time hour during one year i.e. 1560 times per aircraft and ATAgroup. Every time the randomized number is equal to, or less, than the probability factor it will give us a defect, and also which runtime hour the defect occurs. The planned and unplanned tasks were compiled into diagrams were the y-axis represents the amount of tasks, and the x-axis represents days, one diagram for each quarter ofthe year. For examples, see Figure 4.1 or Appendix II. The maintenance tasks is indexed in Table 4.2, see Appendix I for specification of each index

**Aircraft s/n 5 4th qtr 2006**

Sceduled tasks     Unsceduled tasks
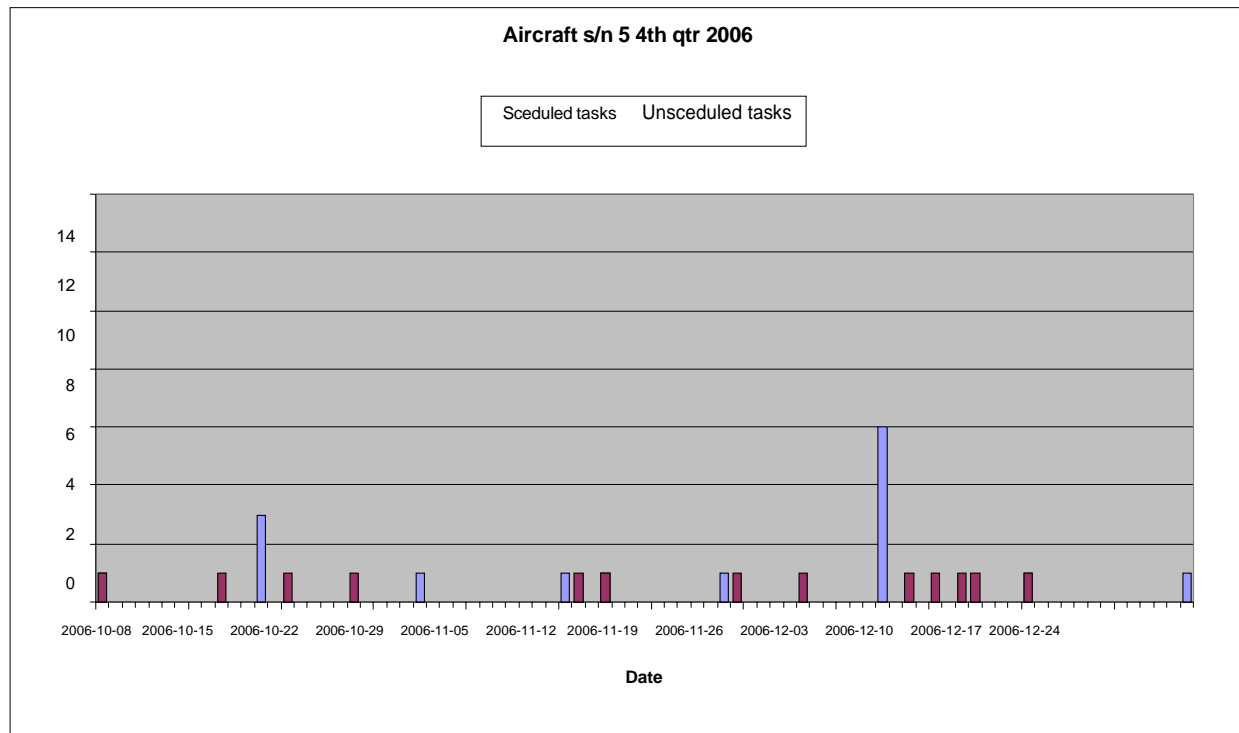


| Aircraft s/n 5  Maintenance tasks 4th qtr | | | |
|---|---|---|---|
| **Date** | **Task** | **Date** | **Task** |
| 2006-10-08 | ATA 25 | 2006-11-24 | a |
| 2006-10-08 | a | 2006-11-25 | ATA 72 |
| 2006-10-17 | ATA 79 | 2006-11-30 | ATA 79 |
| 2006-10-20 | 4,a,b | 2006-12-06 | 2,a,b,e,h,I |
| 2006-10-22 | ATA 32 | 2006-12-08 | ATA 32 |
| 2006-10-27 | ATA 72 | 2006-12-10 | ATA 72 |
| 2006-11-01 | a | 2006-12-12 | ATA 25 |
| 2006-11-12 | a | 2006-12-13 | ATA 72 |
| 2006-11-13 | ATA 25 | 2006-12-17 | ATA 25 |
| 2006-11-15 | ATA 79 | 2006-12-17 | a |
| 2006-11-15 | c | 2006-12-29 | a |

MAINTENANCE DATA ANALYSIS

Maintenance managers and engineers are frequently using the data information that they do collect as the organizations daily work proceeds. They do not, however, share their information with other organizations. Maintenance data are available, but not shared, from many different sites all over the world. If this information is used in an effective manner, it has the potential to be used by maintenance organizations, to gain advantages over their competitors. The best way to accommodate this is, to share relevant information amongst each user which is connected to the regarding system, in a uniform and accurate manner. The information should also be provided timely, to improve its statistic impact. Due to the increasing use of the internet, maintenance organizations can have an on-line access connection to all the supporting information, and can be used by maintenance engineers and managers for analysis and the predicting of any future maintenance requirements. By collecting and performing analysis of gathered maintenance data, the stocking and purchasing process will be supported. To complete the information share task, it should also contain all information on the technical system, and the location of the sharing asset. By this, measurements of the maintenance systems performance and the comparison of the environmental impact of the maintenance tasks can be made.

**Analysis of failure occurrence**

The Poisson probability mass function and cumulative distribution  function  are widely used in the aviation industry since they give a good approximation. Let us take a look at the ATA 32 group as an example:

The total number of ATA 32 incidents in our fleet was 35, MTBF were calculated to 131 hours. For one quarter during one year, the three aircrafts in our fleet flies 1170 hours (TFh).

$\lambda t$ is given by $\lambda t = \dfrac{TFh}{MTBF}$ and by calculating the Poisson probability distribution

function $f(t)$ and the Poisson cumulative distribution function F(t), the following diagram can be drawn:
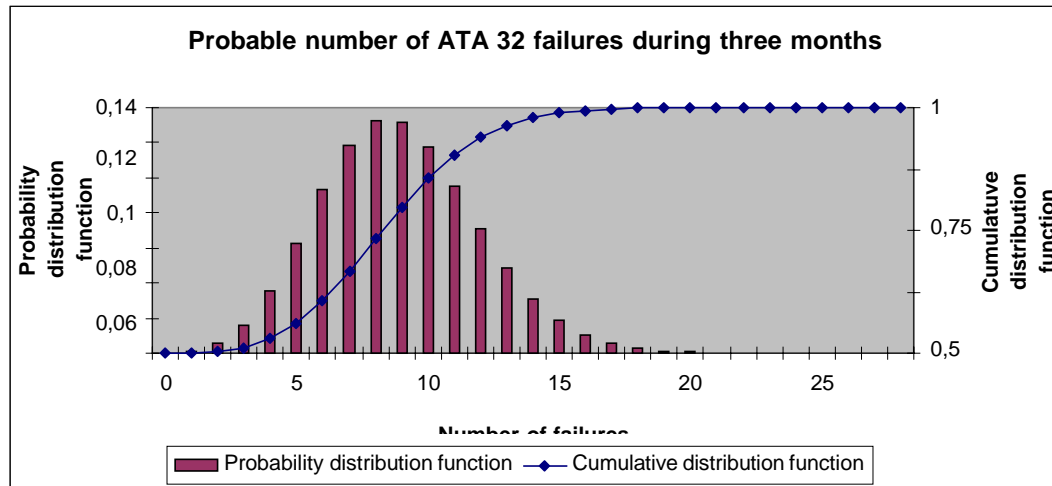


Figure 4.2 Poisson probability- and cumulative- distribution functions of ATA 32 during three months.

It becomes clear how many times this item is likely to fail, and how certain this approximation is. The thinner and higher the probability mass function is, the more certain the prediction is. In this case one may say that it is most likely that this item will fail 7-10 times within the time frame of three months. Based on this information decisions about spares provisioning may be possible to take, even though there are more factors to be considered.

### Analysis of preventive maintenance

There is a need for more information than MTBF to be able to say something about the outcome of for example if extra checks would be profitable, so other measurements which where calculated and approximated was MTTR, MDT, cost of the part needed, cost of repair/hour (labor, facility and VAT) incubation time of failure and finally, the cost of operational losses due to down time. All with reference to the interview, this unfortunately, is our only available source of this kind of information. Thereby, simplifications and assumptions had to be made, especially to fit our minimized sample fleet. A very simple model was developed, based on this information that will help us to see the impact that extra checks would do on the total cost.

Let's say that there are a number of failures expected to randomly occur within a certain period of time, based on knowledge of the past. Then, if extra checks are performed in a given time interval, how likely is it, that one inspection will reveal a failure within its incubation time? Or, as another approach, how many of these failures are likely to be revealed within their incubation time? The last approach seems to give some valuable information, let's keep that track for a moment. If we consider the probability of survival R(t) and failure rate F(t), within a limited time period as an exponential distribution, they would be represented by:

$$R(t) = e^{-\lambda t} \quad \text{and} \quad F(t) = 1 - e^{-\lambda t} \quad \text{where } \lambda = \frac{1}{MTBF}$$

Then, if we know the incubation time $t_i$ for the failure, we can calculate the probability to reveal failures within time $t_i$ from time zero, *see Figure 4.3,* to let's say 14% i.e it's probable that 14% of the failures occurs during that period of time. If we choose to do extra checks at a certain time interval $t_c$, the probability to reveal failures at time $t_c$ would be 14% of the remaining 32% i.e 4,48%.
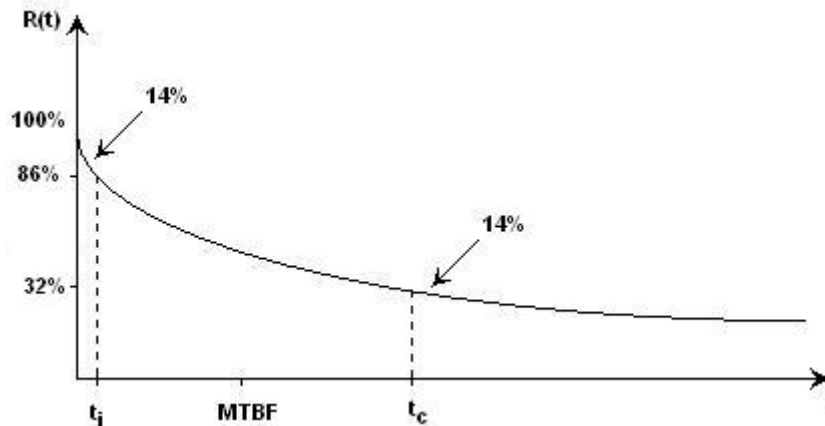


Figure 4.3 Exponential distribution

So, with knowledge of the total flight hours within the time frame TFh, the cost of the unscheduled maintenance i.e down time $DT_{cost}$, incubation time $t_i$, MTBF, how long a extra check would take $C_t$, the interval of extra checks $C_i$, MTTR (to repair the failure), MDT, the maintenance cost per hour $M_{cost}$ and the cost of the part needed $P_{cost}$, we can calculate the approximate savings, or losses, that the extra check would gain.

The number of the expected failures $N_f$ during the period of time represents by:

$$N_f = \underline{TFh\ MTBF}$$

The number of failures probable revealed $F_{revealed}$ will then be

$$F_{revealed} = F(t) \cdot N_f$$

If no extra checks are performed, we assume that all failures occur during or before operation, and therefore, instantly results in operational losses, the total cost would then be approximated to:

$$Tot.c_{no.checks} = \left(MTTR \cdot M_{cost} + P_{cost} + MDT \cdot DT_{cost}\right) \cdot N_f$$

The total cost of these extra checks (repair excluded) can be calculated with:

$$Tot.c_{checks} = C_t \cdot M_{cost} \cdot \frac{TFh}{C}$$

The total costs to repair the failures revealed due to these checks, here we assume that these repairs do not affect on the operational availability, are then:

$$Tot.c_{revealed.f} = \left(MTTR \cdot M_{cost} + P_{cost}\right) \cdot F_{revealed}$$

All failures will probably, and most certain, not be revealed during these checks. So, the total costs for the rest of the failures will then be:

$$Tot.c_{unrevealed.f} = \left(MTTR \cdot M_{cost} + P_{cost} + MDT \cdot DT_{cost}\right) \cdot \left(N_f - F_{revealed}\right)$$

So, to examine if it would give any savings to perform extra checks due to a failure that randomly and frequently occur, we just calculate the difference between the total costs when no extra checks are performed, and the total cost when performing extra checks i.e

$$result = Tot.c_{no.checks} - \left(Tot.c_{checks} + Tot.c_{revealed.f} + Tot.c_{unrevealed.f}\right)$$

| | |
|---|---|
| TFh | 4680 |
| ti | 15 |
| MTBF | 131 |
| Ci | 200 |
| Ct | 2 |
| Nf | 35,72519084 |
| Frevealed | 4,937908654 |
| MTTR | 8 |
| MDT | 10 |
| Pcost | $1 500,00 |
| Mcost | $103,00 |
| Dtcost | $2 000,00 |
| Tot.Cno checks | $797 529,16 |
| Tot.Cchecks | $4 820,40 |
| Tot.Crevealed f | $11 475,70 |
| Tot.Cunrevealed f | $687 295,29 |
| result | $93 937,77 |

This theory was used for ATA 32, we assumed that this failure has the incubation time $i_t = 15$ flight hours and extra checks are performed at an interval of 200 hours, the result is presented in Figure 4.4. The result are in fact not realistic, due to our limitation where we choose to consider the ATA groups as single parts, though there would be a lot of different failures, on different parts. The most common failures in ATA 32 would probably be related to sensors and switches, but if factors based on statistics over a certain failure that occurs randomly and frequent, this model can be, although not perfect, but anyway an approximate tool.

Figure 4.4 Calculation of result with extra checks

To check if $F_{revealed}$ is likely true, we did a validation of these data where the failures randomly where distributed over a certain period of time. And when we relate these data to the extra checks, we can see if we will be able to reveal any failures. *SeeFigure 4.5*, see *the complete set for the fleet in Appendix IV.*
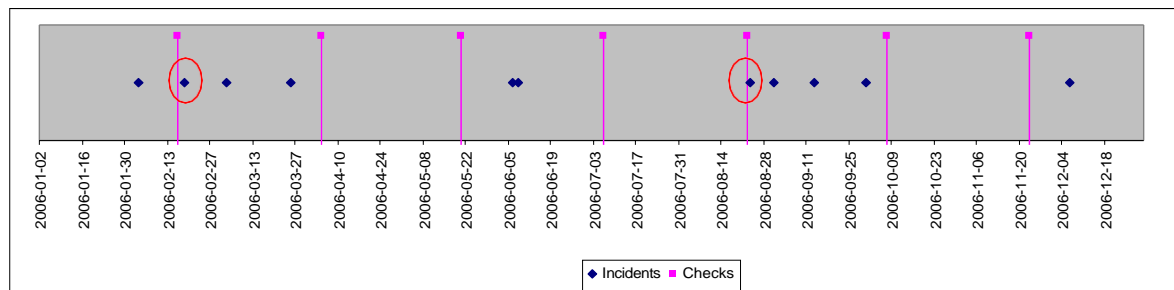


Figure 4.5 The test shows that we probable would reveal 2 out of 11 failures with these extrachecks during a period of three months

These tests were randomized several times, some times we where able to spot up to seven failures other times down to zero failures but most often around three to four failures. So we must keep in mind that this is due to the characteristics of randomization.

### Spares provisioning optimization

So, can this information also be used for spares provisioning optimization? The answer is yes. There are a lot of factors to consider and since the lack of data we will only discuss this theoretically. With knowledge of the estimated probable number of failures for a given time, for example three months *see Figure 4.2*, one may forecast the upcoming need for spares. By considering the parts failure frequencies, MLDT i.e waiting time for spares etc., MTTR, price and the stock holding capabilities it is possible to optimize the spares provisioning. To enlighten this topic, two examples are given as follows:

*Example 1:*

Once again we will refer to Figure 4.2 Lets say that this figure shows the probable amount of failures regarding to gear "down and locked" indicator light bulbs, for the whole fleet. From the figure we estimate that 8 to 9 bulbs will

fail during a period of three months. The price of these bulbs is relatively low and they don't require a lot of stocking space, but the consequence is that the aircraft will not be airworthy until the bulb is replaced, which is a relatively easy and quick task. As a conclusion to this example one may say that the cost of stocking the bulbs constitute a fraction of the cost of aircraft downtime, so the recommendation would be to keep at least 20 to 25 bulbs in stock for the three months period.

## CONCLUSION

Maintenance is a very vast subject which contains of various disciplines and components. In the study, we analyzed the operation and maintenance data for reliability, availability and costs.

The study concludes maintenance task compiling with tasks recognized and divided in to scheduled and unscheduled tasks. The failure occurrences were analyzed and further, a preventive maintenance effect analysis was performed.

All aspects were not considered due to the limited timeframe of the study and the difficulties to receive applicable data. Although, there is scope for conducting further studies of this topic, because, there are benefits to gain if the maintenance records is structured and analyzed in a suitable manner.

This makes the overview of the maintenance procedures and decision making more accurate. Even though the initial cost of restructuring the maintenance record keeping system may be high, it will certainly give a positive impact on the total maintenance cost. For large and medium sized maintenance organizations, a well performing and

purposefully developed software will be a good investment.

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