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Aircraft Maintenance Data Evaluation Method Applied to Integrated Product Development Process

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Abstract

This article presents a method to optimize preventive maintenance tasks intervals and use structured data based on interval optimization process to define maintenance intervals to those of similar systems under development. Initially, select aircraft systems, which can be compared based upon four characteristics: system type of operation, operation system maturity, field data availability/ minimal sample available and data collection feasibility. Then apply the similarity criteria constituted of project characteristics. Furthermore, for those similar systems, it is necessary to collect interval recommendations from following sources: interval optimization process, components reliability information, engineering design and suppliers recommendations and economic analysis. Finally, define the maintenance interval range considering the recommendations and compare to proposed packages to new program. It is possible to define more accurate maintenance tasks intervals as compared to initial MRBR using structured database containing in service operation experience. The proposed method has been applied successfully in a commercial aircraft manufacturer. The definition of more accurate tasks intervals contributes to Direct Maintenance Costs reduction and customer satisfaction after aircraft Entry into Service.

Keywords: Aircraft, Maintenance, Integrated Product Development Process.

INTRODUCTION

In the aviation sector, preventive maintenance is placed as a regulation to assure airworthy condition (FAA, 1998) and it is an extended part of the product, which can be defined as a combination between product itself (material) and related services (Seifert et al., 2011). Initial Maintenance Review Board Report (MRBR) uses in service operation experience as a reference to define maintenance tasks intervals. However, in general, there is no structured data to compare systems performance and provide useful information to the analysts' decision making, who in general select conservative intervals.

Aircraft development is a complex process, which takes longer than the conventional ones and demands higher investments. Small modifications during aircraft certification process or after Entry-Into-Service represents rework, costs increase, customer complaints and product market denigration. Thus, fleet operation under control by Customer Support is able to generate important information to fill product development process. Reducing costs, bringing customers closer, improving products reliability and availability is essential in aeronautic industry to aim higher competitiveness. To use systems operational data as a reference for development can be considered an important tool to reach excellence in products and services offered to the customers.

After accomplish preventive maintenance task, it is possible to collect more than 200 types of data, standardized according to the e-business specification set. However, it is essential organize information so that it can be used in different process in big corporations involving huge department and people quantity. In this context, this paper aims to present a method to evaluate the schedule maintenance tasks accomplishment database, collected and organized by Customer Support Department, in integrated product development processes. The main purpose is to propose reviewed maintenance tasks intervals to systems similar to aircraft under development and reach direct maintenance cost reduction in a short term and customer satisfaction and market recognition in middle term.

This article is organized as follows: The section [Aircraft Maintenance Fundamentals] and [Integrated Product Development] present a literature review of related processes. The section [Proposed Method] presents the new approach to establish tasks intervals to similar systems in operation and development. The section [Results and Discussion] describes a practical application of the proposed method. Finally, the [Conclusion] section presents a brief overview of improvements achieved by the proposed method.

BACKGROUND

Aircraft Maintenance Fundamentals

Brazilian Norm NBR – Brazilian Regulatory Norm 5462 II (Brazilian Association of Technical Standards, 1994) defines maintenance as combination of all technical and administrative actions, including the supervision, aimed to maintain or to replace an item in a status that it can perform a required function. A maintenance requirement is every action periodically performed in order to avoid hazard to an aircraft and passengers in flight or on ground and may have economic or safety impact. In this paper, the terms “task” and “maintenance requirement” have the same meaning.

Initial Maintenance Review Board Report (MRBR) outlines manufacturer’s recommended tasks for airframe, engines (on-wing engine only), systems, components for each aircraft model, and must be approved by Regulatory Authorities. Main worldwide aviation authorities are the Federal Aviation Administration (FAA), for American operators, and European Aviation Safety Agency (EASA) for most Europeans operators. Brazilian authority is ANAC - *Agência Nacional de Aviação Civil*

- which is responsible to control, establish rules and regulate civil aviation in Brazil (ANAC, 2016). The main purpose of MRBR is to maintain the inherent safety and reliability levels of the aircraft and its components. As the aircraft accumulates operating experience it is expected adjustments in order to reach efficient schedule maintenance program.

Aircraft maintenance costs can be classified as Indirect Maintenance Cost (IMC), which comprises infrastructure costs, training, tools, human resources etc., and Direct Maintenance Costs (DMC), in which it is included fuel costs, engine and aircraft maintenance and tools. It is possible to consider there is only intervention from operator or aircraft manufacturer in costs related to engine and aircraft maintenance. For this reason, in order to reach higher customer satisfaction after fleet Entry-Into-Service (EIS) it is crucial to establish adequate maintenance tasks intervals and provide DMC reduction. Adequate maintenance interval means unscheduled maintenance interventions quantity reduction.

In order to establish a standard among aircraft manufacturers, worldwide aviation regulatory authorities defined from 2009 to date some guidelines to evaluate initial preventive maintenance tasks intervals: Issue Paper 44 (European Aviation Safety Agency, 2016) allows commercial aviation manufacturers to evaluate premises before EIS after aircraft started operation and maintenance tasks efficiency in accordance to the authorities' viewpoint.

Integrated Product Development - IPD

According to Pessôa and Trabasso (2016), there are two main approaches for a product design and development process as shown in Figure 1.

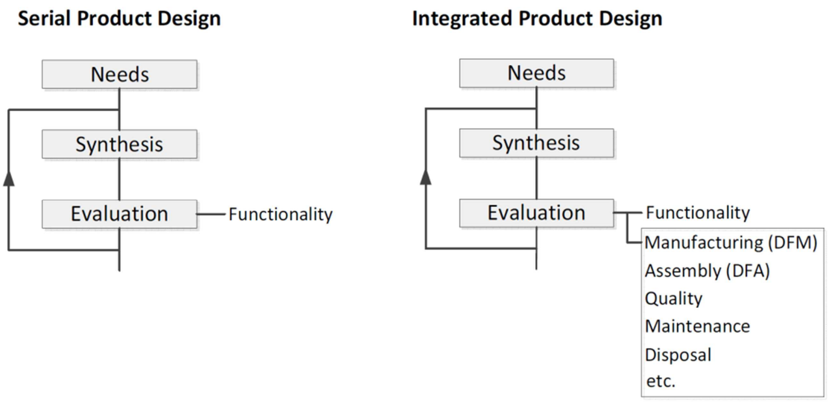

Figure 1: Serial and integrated approaches to product development process

The activities of the serial product development are carried out relatively independently, in a sequential way, where each phase is proceeded until the start of the next phase with limited interaction of the product technical areas. The product is defined, designed, developed and then transferred to manufacturing, testing and commercialization. During the serial development approach, inherited from the 18^{th} century industrial revolution, only the functionality of the product is taken into account at the conception phase, as depicted in Figure 1. Integrated product development instead takes into account all the life cycle of the product: it keeps the benefits from the serial approach (shorten price, shorten time-to-market, augmented quality) while fixes its shortcoming such as reworks, lack of communication amongst technical areas etc. The functionality of a product using an IPD approach will stay the same, but more than that, maintenance up to recycle can be included into the design. IPD prescribes the structuring of two main pillars, namely, multifunctional teams and DFX (Design for eXcellence) design tools such as DFA – Design for Assembly. A typical DFX tool integrates the requirements of the X-technical area (e.g. assembly, use, maintenance etc.) into the conceptual phase of the product development process. The mission of the IPD team is to assure that the requirements of all product development phases are evenly represented in the IPD's conceptual design phase. Ideally, all technical areas from the product lifecycle phases are represented in a typical design team meeting and a number of engineering tradeoffs are raised, discussed, and solved. A requirement from the maintenance area, for instance, might jeopardize the weight target of the product. It is the role of the project leader to ensure the team's focus on the mission and achieve a balanced result for the product.

PROPOSED METHOD

Preventive tasks intervals evaluation is based on Issue Paper 44 – IP44 – (European Aviation Safety Agency, 2016) guidelines and field data collection. The method consists in select aircraft systems, compare system under development and in operation, decide if it is feasible to use field data, and when applicable use operational performance experience (based on preventive maintenance tasks accomplishment) to define new maintenance tasks before fleet entry into service. The system similarity analysis and decision if preventive maintenance tasks accomplishment experience can be used in new Maintenance Review Board Report (MRBR) is based on four characteristics:

1. <u>System type of operation</u>: evaluate if system type of operation is changing in new product under development (e.g. if the aircraft is projected to fly considerable more hours and cycles).
2. <u>Operation system maturity</u>: fleet in operation must present Flight Hours (FH), Flight Cycles (FC) and Months (MO) in acceptable quantity and quality to apply statistical analysis. Sample must contain information using following criteria, before classifying database as acceptable in quality (according to IP44):
   - Task performed to aircraft in different ages,
   - There is geographical representativeness,
   - Sequence task accomplishment to the same aircraft,
   - Unscheduled maintenance tasks related to scheduled tasks: if any non-routine tasks is performed before scheduled task accomplishment, consider it as a finding associated to this scheduled task,
   - Component removals, and
   - Findings (tasks not succeeded) associated to their preventive tasks.

3. Field data availability/ minimal sample available: Minimal amount of data required is known using sample size for finite population calculation (Miot, 2011), since manufacturer is able to measure total amount of executed tasks in fleet.

$$n = \frac{N.p.q.z^2_{\propto/2}}{(N-1).e^2+p.q.z^2_{\propto/2}} \quad (1),$$

where:

n= minimum sample size expected for finite population;

$z^2_{\propto/2}$ = critical value of the desired confidence level (equal to 1.96, equivalent to confidence level of 95%);

p=expected proportion of favorable results in the population;

q = (1-p) = (expected) proportion of unfavorable results in the population;

e= accepted error;

N = finite population size.

4. Data collection feasibility: It is essential manufacturer is able to collect minimal sample required (equation 1) from maintenance tasks accomplishments. In addition it is required data with integrity, which means quality of correctness, completeness, and compliance with the creators of the data (European Aviation Safety Agency, 2016).

The project characteristics are considered in the sequence. The system under development must be compared with system in operation. It is necessary to evaluate if there is project modification in system and subsystem functions, described in System Description and Safety Assessment Reports. Comparison from reports in systems under evaluation and in operation allow analyst to conclude if there are different functions and project characteristics or if it is possible to consider the systems similar. It is necessary to include in this analysis following items: specifications and performance, sub systems part numbers, components materials, and heat treatment to specific cases, product assembly or other relevant information according to analyst discretion.

Then, it is necessary to evaluate field data collected and perform system reliability analysis according to task type as follows. It must be possible to know the task accomplishment result: if the task was well succeeded or not (tasks not succeeded are considered in this paper as a finding).

a) Lubrication and Refueling Tasks: it is necessary to know at the moment of the inspection the lubricant consumption, the component wear, if there are corrosion in relative areas, based on analyzed failure cause. It is necessary to consider intense operational conditions when evaluating deterioration of the components;
b) Functional, Operational or Visual Inspection/ Functional Tasks: analyst needs to verify success rate (total tasks well succeeded) and calculate system reliability using statics model able to estimates system failure probability in a determined time

interval (there are numerous statics model, analyst can choose according to tools availability and personal skill).

c) Restoration or Discard Tasks: In order to evaluate each component condition before system starts to deteriorate it is necessary to create specific program that include all players responsible for the component installation and use (manufacturer, suppliers, operators and aircraft repair shops).

After fulfilling the steps above, it is necessary to collect interval recommendations from different sources. Therefore, each set contains information with different confidence levels, and must be classified and evaluated according to its degree of confidence. The three sets of data are:

- Group 1: low confidence level;
- Group 2: intermediate confidence level;
- Group 3: high confidence level.

The reason why all data is divided in three groups is to guarantee real records collected from identic components based on operational data will be more significant than data based on assumptions due to lack of field data (Group 1) or data based on similar components (Group 2).

Finally, review MSG-3 analysis and select interval considering recommendations. Accomplish economic analysis to tasks category 6, 7 and 9; to those tasks category 5 and 8, evaluate multiple tasks intervals values defined by the program for scheduled maintenance in order to select interval.

Economic analysis consists in:

- Evaluate panels and access to be removed before task accomplishment;
- If the task needs to be performed in line, overnight or only in heavy checks;
- Parts costs in case it requires components removals;
- Estimated labor hour to accomplish task. Consider if it is required interior, engine, APU removal etc.;
- Verify multiple tasks intervals values and if it is possible to include task in main packages.

RESULTS AND DISCUSSION

In order to apply and discuss the results from proposed method, it was selected a detailed inspection of pilot and co-pilot seats. The purpose of this check is to look for degradation, damage and wear in pilot and co-pilot seats. Pilot and co-pilot seats are mandatory in all commercial aircraft and it is possible to consider that their operation is regular and mature, because it is not expected relevant difference on the system in operation and under development in the same manufacturer.

It is evaluated a task which is part of a 6000 flight hours maintenance package. There are more than 780 aircraft in operation with the same system and fleet leader has flown more than 20,000 flight hours. The task type selected is <detailed inspection> because collected data analysis is more objective and does not demand complex analysts' evaluation.

The minimum sample required to perform statistical analysis (n) is obtained from Eq. (1) where $z^2_{\propto/2}$ = 1,96; p=90%; q=10%; e= 4% (for task category 8) and N=2487, that yields n = 199 samples.

Figure 2 presents the expected preventive maintenance intervention distributed in geographic regions for the selected task (detailed inspection of pilot and co-pilot seats), considering fleet operational data.

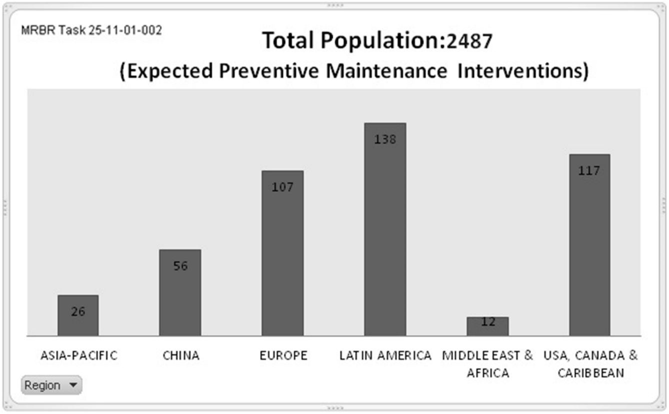

Figure 2: Total Population MRBR Task 25-11-01-002

Figure 3 presents the value of the minimum sample necessary to apply statistical analysis, distributed in geographic regions, for the selected task considering finite sample calculation.

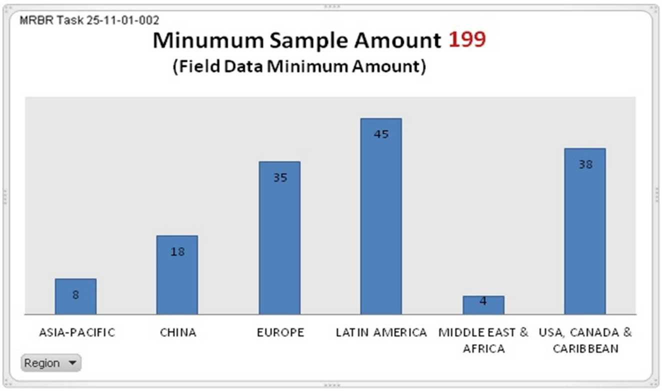

Figure 3: Minimum Sample Amount MRBR Task 25-11-01-002

It was collected a sample of 1077 executions of the task (Figure 4).

Figure 4 shows total sample collected amount, distributed by region, with base on data bank of events associated to the selected task execution. Despite Figure 3 shows it is required 8 events in Asia Pacific, 18 events in China and 4 events in Middle East & Africa, it is possible to consider field data collection acceptable because the system is not affected by environmental factors. It means there is no specific condition in Asia-Pacific, China or Middle East & Africa, which could damage system and justify sample amount discard.

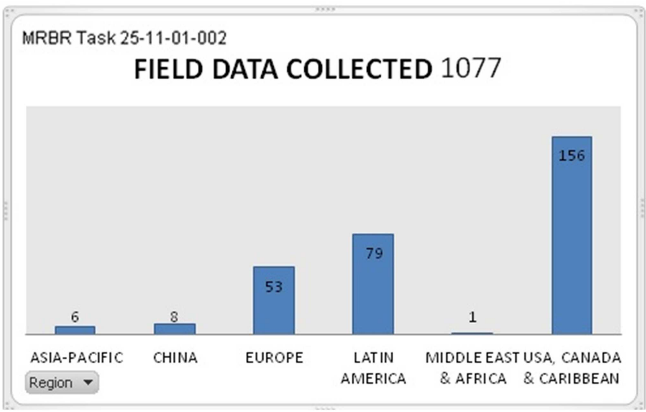

Figure 4: Field data collected - MRBR Task 25-11-01-002

Figure 5 presents the total findings related to task after collected data and after classification (which means findings not related to task were not considered), distributed by region, based on data bank of events associated to the selected task execution.

In order to create the probability function graphic it was used the Action tool, a MS Excel™ supplement. The results obtained are shown in Figure 6.

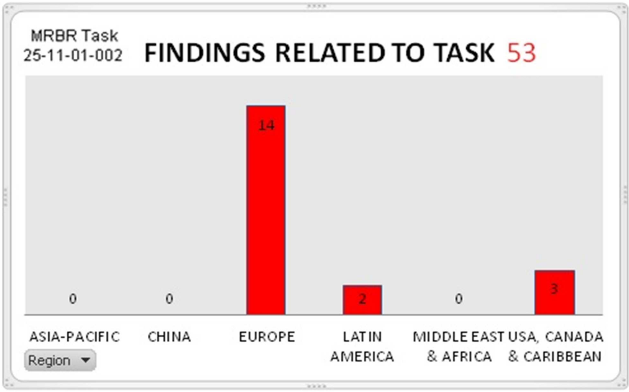

Figure 5: Findings related to MRBR Task 25-11-01-002

Reliability Overview

Process Data

Method	*Distribution*
Maximum Likelihood	Normal

	Estimates	*Standard Deviation*	*Inf. Lim.*	*Sup. Lim.*
Average	40193,1	3212,2	33897,3	46488,8
Standard Deviation	16187,3	1802,8	12653,9	19720,8

Percentages (%)	*Estimates*	*Stand. Deviation*	*Inf. Lim.*	*Sup. Lim.*
0,1	19448,1	1280,5	16938,5	21957,8
0,5	40193,1	3212,2	33897,3	46488,8
0,9	60938,0	5447,2	50261,6	71614,4

Index	*Value*
MTTF	40193,1
Standard Deviation	16187,3
Median	40193,1
1st Quartile	29274,9
3rd Quartile	51111,3

Figure 6: Results achieved through Action Supplement for normal distribution, considering selected the task data.

Statistical assumptions:
Normal distribution, consider n >=30.
Confidence interval = 95%.
Reliability adopted: 85%.
The indicated value for the task, according to the adopted assumptions is approximately 20,000 hours as presented in Figure 7.

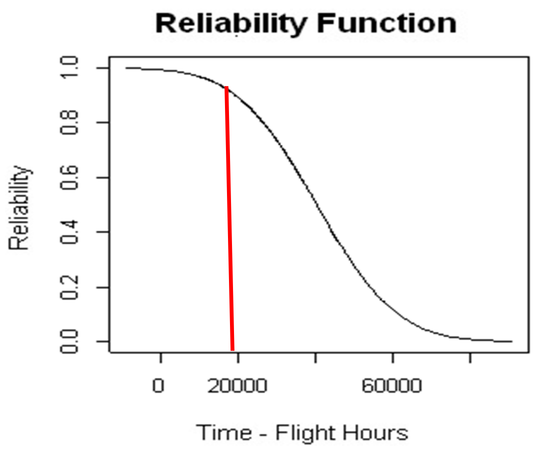

Figure 7: Reliability Function – normal distribution of collected sample.

Table 1 must be filled with the task intervals recommended by each information source. MTBF and MTBUR recommendations were not considered in this analysis because it is not expected pilot and co-pilot seat removals in commercial fleet in operation.

Table 1: Task Intervals recommendations, task 25-11-01-002 analysis.

Information Source	Recommended Interval Value	Group
Recommended MTBF (Mean Time Between Failure) through theoretical data	-	Group 1
Equivalent system's (in operation in different fleets) CMM (not considering the manufacturer)	4,000 FH	Group 1
Recommended MTBF by supplier for similar system	-	Group 2
Field MTBUR (Mean Time Between Unscheduled Removal) for similar system	-	Group 2
Supplier Recommendation for his own system	5,000 FH	Group 2
MTBF based on supplier tests for components under development	-	Group 3
MTBUR of components of identical system in operation	-	Group 3
Task interval of identical/ similar system stated in the MRBR or optimized according to intervals optimization procedure.	20,000 FH	Group 3
Task Interval recommendation made by the Development Engineering	-	Group 3
Task Intervals between tasks executions used in order to certify the system with regulatory authorities	-	Group 3

Figure 8 shows the result of the application of the first part of the interval definition procedure:

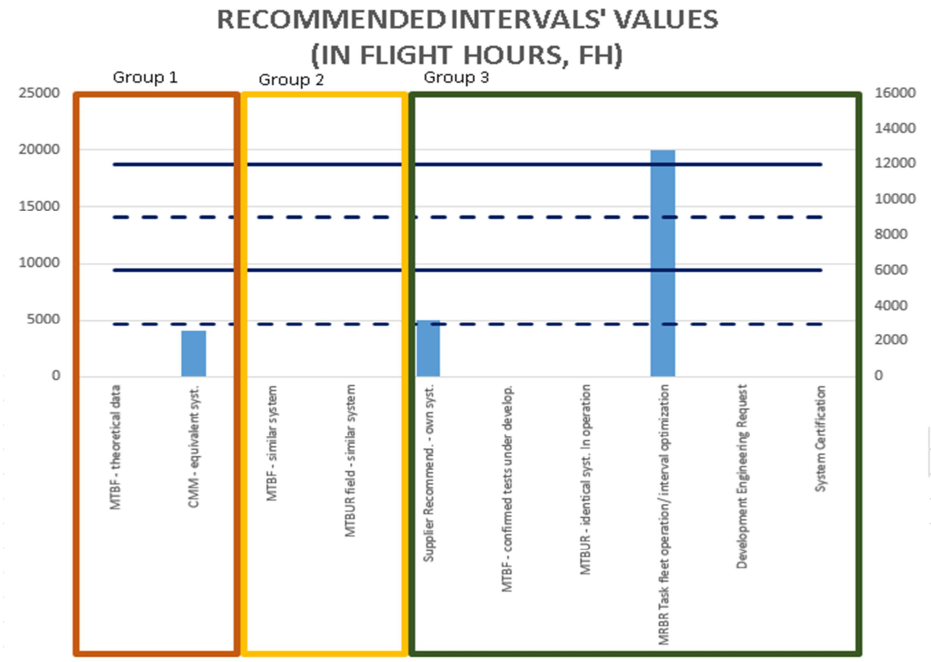

Figure 8: Result achieved by the partial application of the MRBR task interval definition procedure for new system under development.

Considering that the functional failure and the failure effect are classified as category 8 in the MSG-3 analysis, the task selection is mandatory. In this way, the task interval selection is made by maintenance downtime opportunity. For the aircraft under development, the maintenance tasks are concentrated in multiple intervals of 3,000 and 6,000 hours. According to the availability analysis, the recommended interval is 12,000 hours.

Evaluating preventive maintenance tasks based on field performance allows analysts to observe information related to product development process from the concept definition phases until product modification after Entry-Into-Service. Most of the decisions cannot be changed when defining initial the MRBR task interval, however the acquired knowledge might be used to new developments aiming at reducing operating costs and increasing customer satisfaction. A ‘Lessons Learned - LL’ database is highly recommended to influence decisions in Integrated Product Development Process. It might be part of supplier selection process and avoid problems and expenses to Customer Support department, for example. In the LL database, it is recommended to keep the following information: ATA chapter, aircraft, what restricts preventive task interval to increase and concerns in general to Customer Support related to this system. In addition, reviewing this database must be part of Integrated Product Development process.

CONCLUSIONS

This paper has presented a procedure to define System Preventive Maintenance Tasks intervals to new aircraft under development using field data statistical analysis as an important tool and as a complement to the method currently available in the market.

For the case application presented, the task interval fleet in operation is 6,000 hours. The method suggests the interval of 12,000 hours for the fleet under development. Unscheduled interventions quantity reduction in the beginning of fleet operation, however, is the greatest benefit of the method presented herein. It means that in some cases, the preventive maintenance task interval may decrease. In such cases, if the task is not related to safety issues, a cost analysis is recommended.

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