

Impact of RFID technologies on helicopter processes: Assessment on customer oriented indicators

Charlotte Jimenez, Stéphane Dauzère-Pères, Eric Pauly, Christian Feuillebois

► **To cite this version:**

Charlotte Jimenez, Stéphane Dauzère-Pères, Eric Pauly, Christian Feuillebois. Impact of RFID technologies on helicopter processes: Assessment on customer oriented indicators. American Helicopter Society, May 2011, Virginia Beach, United States. pp.AHS, 2011. <emse-00644069>

HAL Id: emse-00644069

<https://hal-emse.ccsd.cnrs.fr/emse-00644069>

Submitted on 23 Nov 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Impact of RFID technologies on helicopter processes: Assessment on customer oriented indicators

Charlotte JIMENEZ^{a,b}, Stéphane DAUZÈRE-PÉRÈS^b, Éric PAULY^a, Christian FEUILLEBOIS^a

^aEUROCOPTER

Marignane, France

[charlotte.jimenez, eric.pauly, christian.feuillebois}@eurocopter.com](mailto:{charlotte.jimenez, eric.pauly, christian.feuillebois}@eurocopter.com)

^bEcole des Mines de Saint-Etienne, Centre Microélectronique de Provence

Gardanne, France

dauzere-peres@emse.fr

ABSTRACT

This paper deals with the introduction of RFID (Radio Frequency Identification) technologies on board of helicopters. These technologies can help to support the traceability of aircraft parts during their entire lifecycle. RFID technologies are widely used within logistics processes. Today, the challenge is to use them to follow the maintenance of parts on helicopters. The chip of RFID tags will store the part identification and the associated usage data. On-board technologies are expensive to embed because of hardening requirements. The development of the information system will also generate a significant cost. To counterbalance the costs, the added value of such technologies within the aeronautical context and the potential improvements for both the aircraft manufacturer and the final operator have to be analyzed. This paper emphasizes the advantages of RFID technologies and quantifies the expected benefits of their integration.

INTRODUCTION

This study concerns the impact of RFID technologies on major aeronautic indicators. The most well-known and used indicators are safety, Direct Maintenance Cost (DMC), Direct Operating Cost (DOC), aircraft availability, customer satisfaction, mission success, Return On Investment (ROI) assessment, and weight impact. The analysis focuses on quantifiable elements and indicators which provide a significant evaluation of maintenance processes. The aircraft availability and the DMC were thus chosen.

Studies led so far concerned the reduction of cycle times or availability increase through configuration changes or process optimization. Analyses about RFID integration focus on logistics aspects or small-scale applications on particular maintenance processes. The following paragraphs give an overview of similar approaches found in the literature.

Strategies for reducing repair cycle times (and as a consequence improving aircraft availability) in naval

aviation depots are examined in [1]. They present a model based on a scenario which concentrates on the repair of aircraft components that are critical to readiness due to short supply. In [2] and [3], the availability of fleets of aircrafts and helicopters, respectively, are modelled. Both of these papers consider battlefield operations. In our case, only the civil fleet of medium size helicopters is considered. In [3], a simulation model is designed to estimate the MCR (Mission Capable Rates) for different military aircraft modernization schemes. The threshold to meet the availability requirement is based on an expected 75% rate due to new aircraft configurations. Mission Capable Rate lower than 75% corresponds to a high-risk assessment in a battlefield context. A simulation approach is used to estimate the availability of operational aircraft in war situations.

[4] propose a discrete event simulation model for analysing maintenance operations in an uncertain operational environment. It provides the effect of maintenance policies on the overall performance of the aircraft fleet.

In [5], a simulation model is used to analyse the combat maintenance operations of a helicopter fleet. In [6], a discrete event simulation model for the operations of an aircraft fleet during peacetime is constructed. The model describes the accumulation of the flight hours, failure occurrences, and regular maintenance and failure repairs.

The model inputs are based on real collected data. The simulation model aims at identifying critical paths and turnaround times in maintenance under normal activity. It concentrates on the daily flight policy and potential rearrangements of the maintenance system.

The referenced articles show that assessment of aircraft availability has been studied in the literature. In our study, we apply the same kind of methodology as [6] to our specific case. To our knowledge, no previous research was performed on modelling and analysing the impacts of new communicating technologies such as RFID on aircraft availability. Previous studies focused on aircraft changes or process improvements. The introduction of new technologies was not assessed so far.

Concerning the Direct Maintenance Costs (DMC), in [7], maintenance activity durations and associated man-hour expenditure contribute to the DMC. The evaluation of maintenance activity times and particularly fault diagnosis activities provides a cost-effective approach. [8] conduct the same approach through design and fault diagnosis assessment of the impact on the Direct Maintenance Cost. This indicator can be used for competitive reasons when there is a purchase or a lease of an airplane. It allows the calculation of production variance, marketing variance and expected idle passenger capacity in the airline industry [9]. The evaluation of cost effectiveness of helicopter EMS (Emergency Medical Services) for trauma patients was done in [10]. The costs estimate Direct Operating Cost (DOC) and additional survivors' hospital costs. Cost per life saved and discounted cost per year of life were the main outcome measures. DMC studies also reflect the maintenance costs evolution (increase) with the aircraft age [11]. Studies on the Direct Maintenance Cost (or Direct Operating Cost) do not estimate the global maintenance cycle. Some of them concentrate on the fault diagnosis while others use these indicators for business approach or profitability estimation.

Section 1 details the potential improvements on the global maintenance process. Section 2 and 3 concentrate on the integration of RFID technologies on board and the associated integration constraints. Section 4 presents the benefits expected from the introduction of RFID technologies.

POTENTIAL IMPROVEMENTS IN MAINTENANCE PROCESSES

Maintenance paper forms

Nowadays, maintenance actions face several problems in particular with log-card processes. The log-card is a paper form which has to be filled each time a configuration change is performed or a part removed. Indeed, this paper form follows the part and exists for legacy reasons. It tracks the part (information of identification) and the maintenance history (usage data, helicopter on which the part is installed, reason for removal). The paper can be used by everyone at any place and in any condition. No special tool is needed and it is one of its strength. A major disadvantage of this

traceability is that the paper can be lost, the information not complete or inaccurate. This could lead to serious consequences like scrap of parts due to a lack of information not recovered, waste of time, large storage area used for pending parts. The remaining potential of flying parts must be updated for parts submitted to preventive maintenance. Associating information to a part could lead to a better sharing of potential when the part operates on several aircrafts. The direct access to the part information by any maintenance actor will allow a good traceability of the value chain.

Logistics for maintenance

The replenishment of parts and the reverse flows can also be improved by a better traceability of parts and an anticipation of needs. The flow of a part is not always controlled from the departure point to the arrival point. Within the logistics process, improvements for spare part shipping and for stock level anticipation will be significant through the introduction of RFID technologies.

Maintenance support

The assistance during the maintenance action will lighten the workload of people. Workers will spend more time on core competency actions and much less on filling paper forms or on recovering lost parts. Most of the maintenance errors are related to inaccurate data, incorrect installations of components or lack of inspection or quality control.

Tools management

Maintenance tools can be identified and tracked. The traceability of input/output movements, the knowledge of use times and number of uses can be widely deployed thanks to efficient technologies for traceability. The calibration information can be stored and accessible for tool maintenance actions.

Configuration management

Several stages exist for the configuration management. At first, the customer expresses his aircraft needs (mission, optional, performances ...). The configuration "as designed" is given to the production centre. Quality responsible has to fit with this theoretical configuration. This configuration is composed of the assembly of the "basis", optional required for the customer missions and the customizations related to specific wishes of the customer. The resulting configuration is called "as built" configuration. This configuration is available in the Enterprise Resource Planning (like SAP) because data are updated at each step of the assembly process. During the production phases, the configuration is updated when events occur (failing components, expiry date achieved...) before the end of the assembly. The configuration "as delivered" is then provided to flight tests. They perform several flight hours to burn-in all aircraft systems and to validate the ability to fly. Then, the global configuration "as delivered to the customer" is ready to be checked.

The access to the customer configuration is not always easy. Indeed, in service aircrafts are submitted to maintenance actions and configuration updates to insure specific mission constraints. A helicopter is made up of a very large number of parts (several hundreds). Unlike airplanes, helicopters can ensure several kinds of missions such as offshore, Emergency Medical Service, VIP, aerial work, etc. An aircraft has to be customized to ensure such missions. The configuration of a helicopter can thus vary in a wide range and is called “as operated” configuration. Optional components can be added or removed and parts can be changed to support the next mission. The configuration can vary daily and parts can be exchanged between aircrafts. The follow-up and the management of these configurations can be complex. Maintenance operators are not the same between maintenance actions, in the same place and the access to the information is not easy. For both the OEM and the operator, the knowledge of aircraft configuration (“as maintained”) is critical and could be drastically simplified and improved in terms of reliability thanks to RFID technologies. Each configuration modification has to be tracked for safety, maintenance and availability reasons. The control of this information is a key and traceability technologies can ease the gathering of information. The precise and real-time control of the aircraft configuration allows the equipment conformity to be checked. The data are more accurate, the effort is reduced as well as human errors related to paper forms. Configuration databases are also able to provide statistics on embedded parts. Tracked items will benefit from an information update and lessons learnt.

Maintenance planning

The flexibility of maintenance actions plays a large role in aircraft availability. The right sharing of resources enables to minimize the immobilization of parts. The anticipation helps to plan the right worker with the right skills, the adapted tool, available spare part, and available space in time, etc. RFID technologies can thus reduce maintenance cycle times.

RFID GLOBAL CONCEPT

Currently, the best technology identified for ensuring such an ambition is RFID. This technology has the features to support these potential improvements.

RFID technologies: General description

RFID components are able to communicate in a wireless way. RFID tags are composed of a chip which contains data. This chip is connected to an antenna. It allows information to be exchanged with an interrogator module through a radio wave signal. The packaging protects the tag from environment damages. Unlike bar code, information contained in RFID tags can be modified and updated. If the part is ageing, usage data can be updated. Data inside the tag or in an associated database can provide real time information concerning the tracked part.

Adaptation to aircraft use case

In the aim of managing “as maintained” configuration, RFID tags will be affixed on the parts that are traced. They contain the same data as the current log-card. As mentioned before, the log-card is the paper form following the part during the maintenance processes. Tags will contain information about the parts (identification and maintenance data) as specified in the aeronautical standard for RFID (ATA Spec 2000 Chap 9.5 [12]). This kind of data will help configuration management and also maintenance processes. The concept of e-maintenance will be supported by the gathering of every digital data [13]. To integrate RFID tags on board, several requirements must be satisfied. In Europe, EASA (European Aviation Safety Agency) ensures the airworthiness and the certification of parts. For the American continent, the FAA (Federal Aviation Administration) manages this problematic.

To be put in an aircraft, a part has to follow the regulations and to resist to harsh environments. Requirements according to “the environmental conditions and test procedures for airborne equipment” must be respected. Rugged technologies will resist to harsh conditions like temperature, vibration, humidity, sand and dust, lubricants, electromagnetic aggressions, etc. The test results will exhibit the availability (or unavailability) of the technologies to handle aeronautical conditions of life. These requirements concern not only the tags but also all embedded elements implied in the RFID system.

Suppliers and research laboratories are adapting several RFID technologies to handle aeronautical requirements. A data security level will also be integrated. This will protect the tag from data corruption or counterfeit.

Aircraft implementation / integration constraints

Embedding RFID tags and reading systems (in a meshed network [14]) requires to optimally position the various components. A global RFID system positioning is complex because each tag has to be read (whatever distance or space restrictions), global weight has to be constrained and cost has to be minimized. There are other constraints which are taken into account for aeronautical integration: weight constraint, cost constraint, and aircraft architecture.

A research project lead by Eurocopter and supported by French suppliers is performed nowadays. The project embeds a complete RFID system for gathering configuration data. Data will be stored into a concentrator unit automatically without human intervention. The objective is to bring down technological breakthroughs for tags, readers and the data concentrator. Environmental tests showed that the performances are good enough to resist to helicopter conditions and environment. Metallic parts reflect waves and reduce read/write performances. Confined surroundings decrease the propagation distances because of wave interferences. Tags and antennas are developed in a way that the communication in those particular conditions is ensured

and optimized. Such performances need an electromagnetic simulation based on the Digital Mock-Up of the aircraft associated to relevant materials of parts (e.g. type of material).

Aircraft manufacturers are interested by technologies for traceability. Several examples can be recently found in the Press. Airbus, Boeing, Turbomeca, Dassault make a significant effort to integrate traceability technologies in aircrafts. This shows that traceability issues are motivating and innovative for aircraft industries. Problems faced by helicopter manufacturers (mentioned above) can also be found by aircraft manufacturers and other suppliers.

The embedded concept

The global concept is to embed RFID tags, readers and a Data Concentrator Unit (DCU) into the aircraft. This meshed and secured network will update in real time information in the tags. Identification and usage data will be attached to the tracked parts and secured. All data coming from embedded tags will then be pushed out of the aircraft. They will be stored in dedicated databases for shared applications.

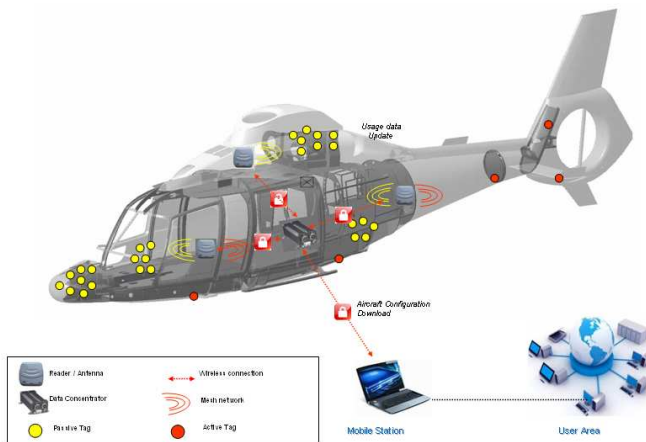


Figure 1 : RFID global concept in a helicopter

At first, this project started to support the traceability of products and their in-service follow-up. After these first objectives, people understood that the project could lead to significant improvements via the knowledge of the in-service configuration.

ADVANTAGES OF THE GLOBAL RFID SYSTEM

Impacts on the global maintenance management system

Aircrafts, and in particular helicopters, often change their configuration during their lifetime. According to mission constraints and maintenance actions, parts are installed and removed from the aircraft. Configuration management means that every change in the configuration must be identified and tracked for safety reasons and also for inventory management. Sometimes, the operator does not reference the information into the maintenance management tool at the right time. He can wait to have enough time to fill

the paper forms (e.g. at the end of the work day). Thus, the configuration “as maintained” (the one present into the maintenance management system) differs from the configuration “as flight” (the one which is really flying). This difference will not longer exist due to RFID technologies, because information will updated in real time.

Configuration management at the customer side

After the delivery, the customer is flying and modifies the configuration of its aircraft. The configuration management relies upon digital files for large customers or simple files for smaller ones. For some customers, this configuration is regularly updated into the Maintenance Information System (MIS) like a CMMS (Customized Maintenance Management System). The follow-up of the configuration changes is mandatory for legal and safety reasons (Part M claimed by the EASA) [15].

The maintenance management system allows this tracking by merging all configuration data when a modification occurs. This maintenance management and planning tool also records usage data (flight hours and flight cycles) for usage follow up of each part.

The MSR (Master Servicing Recommendations) indicates at which time (or usage level) parts have to be replaced or repaired. It is compared to the file downloaded from the data concentrator for determining maintenance expiry date of parts submitted to preventive maintenance. The maintenance management system also delivers maintenance plans considering the operator missions and constraints.

The data downloaded from the aircraft can be sent to the maintenance tools. The objective of the project is to demonstrate the availability of the RFID system to provide a file with a standardized format. This file will be integrated into a MIS for a demonstration. The comparison between these two files is drawn to identify a delta. Thus, the problem is identified and localized by the maintenance operator. To respect the end-to-end chain, the demonstration at the end of the research project shall reach the level of maturity TRL 6 (Technology Readiness level). This indicator is used to assess the maturity of technologies. Level 6 reveals that a representative model or a prototype system is tested in a relevant environment.

Part traceability

The system will update usage data after each landing (or each manual update by a maintenance operator). No lack of information will be allowed and a warning will be raised in case of error in update. This concept will digitize and improve accuracy of the current paper log-card to decrease problems detailed in section “Improvements in maintenance processes”.

The part will move in the logistics process with necessary information attached. Appropriate data will be stored in the tag and will reveal the part flow. Data will not

be the same as identification and usage needed for the maintenance process.

The automated update of information will avoid time losses such as looking for parts and tools, filling forms, i.e. non value added activities.

Moreover, the associated database will facilitate the access to the needed information without any physical presence of the aircraft. Indeed, aircrafts are sometimes operated in a remote location and their maintenance updated and managed somewhere else.. Maintenance shops will also benefit from databases because they will have access to usage data, part version and status of the part (in logistics, in stocks, under removal).

Configuration management in maintenance processes

After a maintenance plan has been established, aircraft parts have to be maintained at their due dates. There are three levels of maintenance shops depending on intervention complexity (see [16], [17] and [18]):

- O-Level: Operating Level. It corresponds to aircraft preparation, current tasks, quick and simple repairs. They are realized at the customer's premises.
- I-Level: Intermediate Level. It corresponds to maintenance which requires moderate means, specialized shops, tools and specific skills for the employees.
- D-Level: Depot Level. It corresponds to major overhauls with qualified labour.

According to the level(s) involved, the part time unavailability varies. In most cases, parts are changed and the removed ones are sent to the appropriate repair shop. Serial Number and sometimes Part Number change. All information must be updated in the log-card and also in the Customized Maintenance Management System.

QUANTIFICATION OF THE BENEFITS

RFID technologies are expensive compared to other technologies for traceability. For instance, bar codes are only printed and do not require major investments. RFID technologies already induce larger investments when introduced in industrial processes. In the aeronautical context, RFID technologies have to be adapted to meet airworthiness requirements. This hardening will considerably increase costs. A cost/benefit analysis needs to be performed to define the Return on Investment of RFID technologies.

As RFID tags will be on board, the impacts will not only be on logistics aspects (a common use of RFID) but also on maintenance processes. The information about maintenance will considerably help from aircraft delivery by the OEM (Original Equipment Manufacturer) to the entire lifecycle of each aircraft component.

The study presented in this paper is customer-oriented and emphasizes on their benefits. In the frame of the analysis performed, the work focused on the impacts of the implementation of RFID technologies for the customer. In [19] and [20], improvements for the helicopter manufacturer were detailed.

For a representative estimation and quantification of RFID integration, we focused on the important indicators for both the OEM and the customer. The measurements led in [19] and [20] assessed the improvements for the aircraft manufacturer. The D-level maintenance actions were the first studied and detailed. This process was well identified and deeply mapped because it is performed in Eurocopter premises.

The analysis of the aircraft performance indicators showed that the DMC and the availability are impacted and improved thanks to the introduction of RFID technologies. After these good results, the customer processes were identified and analyzed. The customer tried to find out what could be improved thanks to RFID technologies in the different processes and particularly during their maintenance actions. The O and I-level were clearly detailed. The analysis presented in this paper was led on the O, I and D-level of maintenance processes.

Notions about availability

Aircraft availability is "the measure of the degree to which an item is in an operable and committable state at the start of a mission when the mission is called for an unknown time" [21]. This system performance parameter provides insight into the probability that an item or system will be available when required. The operational availability should not be confused with inherent availability and achieved availability which are measured under ideal conditions.

$$\text{Availability} = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}}$$

To determine the availability of the system or of the global aircraft, the typical method is to determine or to observe the equipment state over the time and to estimate the ratio of uptime to total time. The ratio is based on the available or unavailable state. The uptime refers to the operating time and the standby time. The downtime is associated to the unscheduled downtime and to the scheduled downtime [22].

The availability is calculated as a function of Mean Time Between Maintenance (MTBM) and Mean Down Time (MDT). MDT is usually defined to include downtime associated with all kinds of maintenance and includes logistic and administrative delay. It comprises all possible events which cause an item to be unavailable, without restrictions. The problem of this equation is that unscheduled and scheduled maintenance are not separated. The distinction was made in the simulation. Different maintenance downtime and time to maintenance are

considered according to corrective and preventive maintenance.

Input data

The availability modelled in this paper takes into consideration the O, I and D-levels of maintenance actions. All kinds of aircraft parts are considered in the simulation. It reveals the tasks for mechanical and avionic parts. The reliability of parts, the logistic support and the transition times are considered (or assessed) in the modelling.

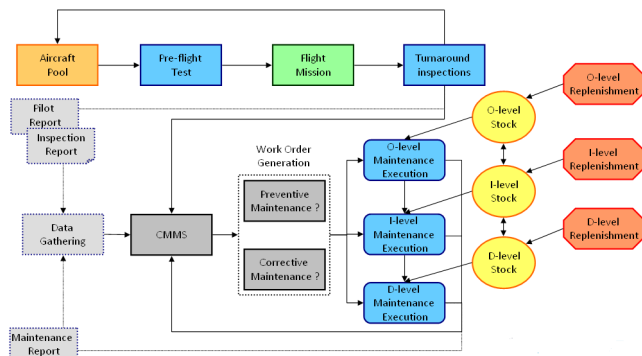


Figure 2 : The maintenance process for helicopters (preventive and corrective maintenance)

Times spent at each step of the various levels were collected. The study went into details of the time monitoring of each task. The times spent for installation or removal of a part and the associated checks were assessed. The residual time was also considered like the documentation time (looking for a work-card or filling the paper forms after the maintenance action).

For the O-level, I-level and D-level, the impact of RFID technologies was estimated with experts and maintenance operators. The daily work was also observed and the processes mapped in details. For the O-level and I-level, figures were obtained on the time spent for maintenance tasks (checks, replacements or small repairs). The I-level analysis focused on the MMH/FH (Maintenance Man Hours per Flight Hour). The data on the MMH/FH correspond to the time spent by the customer or the aircraft operator to prepare some maintenance actions. Available data were theoretical (standard execution of tasks) and real ones (difference due to the search for tools, documentation filling-in, and difficulties during the maintenance action). It concerns the tasks performed just before a SLL (Service Life Limit) or a TBO (Time Between Overhaul) for instance. It gives the spent time to install or remove a part and all the related actions (check, cleaning, bonnet opening, level verification, etc.). The D-level was described in details. All repair and overhaul tasks were identified and the associated times established. For all simulation stages, mean values as well as boundaries were determined. Data were based on reality or experts' knowledge. For a realistic study, 420 instances were simulated to insure the stability of the results.

For each day, flight hours are chosen according to the customer missions. For each flight, the probability of maintenance action (preventive or corrective) was estimated with realistic figures.

Availability model

The comparison between the maintenance needed time and the available time between flights is performed. If the available time between flights is not sufficient, the unavailability to realize the mission for maintenance reasons (mandatory actions) is taken into consideration. Thus, the global availability of the aircraft is considerably decreased. The modelling considers a delay because the aircraft is not available enough for the mission. This is thus really penalizing for the aircraft mission. The impact has been taken into consideration in the modelling. Operating availability does not reflect the insufficient time for maintenance. Indeed, as the model works, the operating time is the total time minus the necessary maintenance actions. It does not take the needed operating time (which could be more important than the operating available time). To penalize more the global availability of the aircraft, the available operating time is decreased by the necessary part of maintenance time compared to the "allowed" time to perform it. The real availability is decreased compared to the necessary availability. The more the difference is important, the more the availability of the aircraft is impacted.

Thanks to these realistic values, we have plotted the benefit of the RFID usage into maintenance processes.

Direct Maintenance Cost

The Direct Maintenance Cost (DMC) is one of the major aeronautical cost indicators. Maintenance actions like repair and overhaul represent large cost drivers for the aircraft operator. Reducing this part of the lifecycle costs is really important and plays a role in competitive actions. The DMC is used a lot as a statistical figure that varies with the type of mission carried out by the operator. The DMC is expressed as a cost per flight hour, which reveals the expenses generated by a flight on direct maintenance. These costs do not reveal indirect maintenance cost, insurance, fuel, or end-of-life costs.

The DMC is taking into consideration both preventive maintenance and corrective maintenance. It includes direct costs allowing the maintenance of a system. It concerns spare parts, consumables, repair and replacement labour costs and tool depreciation [23] and [24]. For a global view, it can be separated in:

- Technical labour (due to preventive or corrective maintenance)
- Spare parts and consumables costs

The maintenance process was analyzed and maintenance costs were assessed for the DMC calculation.

Details on DMC

The DMC is the sum of two parts (Eq. 1). The first part of the expression corresponds to preventive maintenance, and the second part is associated to corrective maintenance.

$$DMC = \frac{\textit{Preventive maintenance Cost}}{\textit{Expiry date}} + \frac{\textit{Corrective maintenance Cost}}{\textit{MTBUR}} \quad (\text{Eq. 1})$$

The preventive maintenance cost per flight hour is defined as the ratio between the maintenance cost and the time between two preventive maintenance actions (replacement, check or overhaul according to the part considered). The corrective maintenance cost per flight hour is defined as the ratio between the maintenance cost and the time between unscheduled maintenance actions (MTBUR = Mean Time Between Unscheduled Removals). The MTBUR (Mean Time Between Unscheduled Removals) reflects the corrective maintenance actions. It considers the Not Fault Found rate which means that a functional part can be removed by mistake.

To improve the DMC, maintenance costs (preventive or corrective) have to be managed and reduced. In the same objective, time between maintenance actions should be improved.

Our study focuses on maintenance costs for both preventive and corrective maintenance actions.

Modelling the gain provided by RFID technologies

As mentioned earlier in this paper, RFID technologies have a great incidence on time savings. The introduction of RFID helps to reduce maintenance costs and thus decreases the DMC. RFID technologies will impact several aspects of maintenance processes. This work focuses on labour reduction and task force optimization (reallocation of workers). Earnings have been observed at DMC level. The DMC is hardly influenced by D-level maintenance actions and therefore OEM repair and overhaul costs.

DMC can be detailed as follows:

$$DMC = \frac{\textit{Overhaul mtc Cost}}{\textit{Overhaul Expiry date}} + \frac{\textit{Replacement mtc Cost}}{\textit{Replacement Expiry date}} + \frac{\textit{Repair mtc Cost}}{\textit{Repair MTBUR}} + \frac{\textit{Replacement mtc Cost}}{\textit{Replacement MTBUR}} \quad (\text{Eq.2})$$

Overhaul and replacement costs (in bold font) correspond to preventive maintenance that happens regularly. When an overhaul of an assembly is performed, it implies more spare parts than when a replacement of parts is done. Overhaul also implies dismantling, inspection and reassembly. The replacement of a part by a new one is easier. Overhaul maintenance will benefit more from RFID technologies than replacement maintenance.

For corrective maintenance, the same reasoning can be applied. Repair will be more impacted by RFID technologies than replacement. However, for replacement in a corrective maintenance action, additional time is needed. Corrective maintenance may require more man hours around the task itself. For instance, corrective maintenance sometimes claims more labour time because of failure location and No Failure Found Rate (NFFR). Thus, for replacement maintenance cost, RFID technologies have more impact on corrective maintenance.

As previously detailed, the Direct Maintenance Cost can be separated into technical labour and spare parts. Thus, we have:

$$\frac{\textit{Overhaul mtc Cost}}{\textit{Overhaul Expiry date}} = \frac{\textit{Overhaul Labour Cost} + \textit{Overhaul Parts Cost}}{\textit{Overhaul Expiry date}} \quad (\text{Eq.3})$$

$$\frac{\textit{Replacement mtc Cost}}{\textit{Replacement Expiry date}} = \frac{\textit{Replacement Labour Cost} + \textit{Replacement Parts Cost}}{\textit{Replacement Expiry date}} \quad (\text{Eq.4})$$

$$\frac{\textit{Repair mtc Cost}}{\textit{Repair MTBUR}} = \frac{\textit{Repair Labour Cost} + \textit{Repair Parts Cost}}{\textit{Repair MTBUR}} \quad (\text{Eq.5})$$

$$\frac{\textit{Replacement mtc Cost}}{\textit{Replacement MTBUR}} = \frac{\textit{Replacement Labour Cost} + \textit{Replacement Parts Cost}}{\textit{Replacement MTBUR}} \quad (\text{Eq.6})$$

We define a model which considers labour gains on the global DMC (Eq.2) and calculates the ratio between DMC with RFID and DMC without RFID. More details on the DMC model and ratios cannot be given for confidentiality reasons.

Details on Cases considered in the study

Each part in an aircraft can be allocated in one of the four following cases.

- **Case 1. Preventive maintenance.** Consideration of **Replacement** by a new part. Both preventive and corrective maintenances are considered because parts which are submitted to preventive maintenance can also follow the corrective maintenance process. The equations used are Eq. 4 and Eq. 6.
- **Case 2. Preventive maintenance.** Case of Repair and Overhaul of parts. As before, a part which is under an overhaul expiry date can face a corrective maintenance action. The equations used are Eq. 3, Eq. 5 and Eq. 6.
- **Case 3. Corrective maintenance.** A corrective maintenance can occur but the part is repairable. The model considers a certain “percentage of reparability” of parts because they may also be damaged and thus be exchanged. The considered equations are Eq. 5 and Eq. 6.
- **Case 4. Corrective maintenance.** A corrective maintenance for only replacing a part by a new one. It often occurs because many parts are not submitted to preventive maintenance and are not repairable. The considered equation is Eq. 6.

RESULTS

Availability study

In the analysis, impacts on stocks, O-level, I-level and D-level of maintenance are plotted.

Stock impact

For the stock level, improvements concern the percentage of availability of resources (material or human) in the simulation model. The introduction of RFID technologies will facilitate the anticipation of the maintenance action and thus the needed parts and qualified people to perform it. The spare waiting time will also benefit from the introduction of RFID technologies because the order will be launched earlier.

O-level impact

At this level, the transit time between shops will be reduced. The availability of parts and tools will be planned with a good anticipation. Knowing in advance the part to be maintained will reduce the transit. The maintenance execution time will benefit from the introduction of RFID technologies. Indeed, paper form filling and looking for tools or technical documentations represent a large part of the maintenance cycle time. Direct access to the appropriate tool, information and automatic form filling will facilitate tasks of the technical staff.

I-level impact

The I-level is really close to the O-level, i.e. the advantages of RFID technologies are concerned with the same stages of this process. Transit time and maintenance cycle time are longer but the percentages of gains remain in the same order of magnitude.

D-level impact

Impacts are more important at the D-level. They concern more phases of the total D-level cycle. The transit time is strongly impacted because logistics aspects improve very much through RFID traceability. A running project within Eurocopter has already shown good results. The filtering of a part or an assembly is time-consuming. It ensures that the part (or the assembly) really corresponds to the paper form sent, recovers the missing information and contacts the consumer if problems are faced. The lack or inaccurate data slows down the overhaul process. There are many financial losses because of these problems. A significant improvement can be achieved with a digital dataset associated to the part. It is sometimes named “e-log-card”. The expertise, overhaul and reassembly times will be improved. Tool location, documentation and maintenance reports can be greatly shortened during the maintenance execution. Out of the scope of RFID improvements are the dismantling time, cleaning time, paint removal time and also testing time. These actions are well known by the technical staff and cannot be improved via digital traceability.

Table 1. RFID impacts on process cycles.

RFID improvements (Maintenance Cycle Time)	Stock	O-level	I-level	D-level
5 %	1.67 %	0.25 %	0.37 %	9.38 %
10 %	3.33 %	0.27 %	0.40 %	13.56 %
15 %	4.95 %	0.28 %	0.42 %	17.72 %
20 %	6.52 %	0.30 %	0.46 %	21.70 %

The maintenance cycle time earnings are shown in Table 1. The first column gives the hypothetic impacts on maintenance tasks (5 to 20 %) with RFID introduction. Other columns reflect the impact according to the improvement on Stocks, O-level, I-level or D-level respectively. The figures at the D-level show that the impact is bigger than the “RFID improvement”. It is justified by the fact that several gains are added. For the time of filtering and the material research potential benefits are larger than 20%. That is why the global impact exceeds the RFID improvements. As the D-level was studied thoroughly, earnings at this maintenance level are well justified.

Table 2. RFID impacts on aircraft availability.

RFID improvements (Availability)	Stock	O-level	I-level	D-level
5 %	0.75 %	0.12 %	0.19 %	3.86 %
10 %	1.42 %	0.14 %	0.20 %	5.80 %
15 %	2.21 %	0.14 %	0.21 %	7.70 %
20 %	2.88 %	0.14 %	0.22 %	9.20 %

Table 2 focuses on the availability improvement. The assumptions are the same than for Table 1. This analysis shows that the improvements at the D-level are the most impacting on the global availability of the aircraft. The results correspond to the average of 420 instances ran in the simulation model. They reflect a global assessment and not some particular simulated cases.

DMC study

In this study, we analyse all configurations faced in aircraft maintenance. It can be submitted to the MSM (Master Servicing Manual) and also face unplanned maintenance actions. Some parts are not under planned maintenance but can enter the maintenance process.

In the frame of this work, several scenarios were plotted for sensitivity analysis to provide a better overview of the model behaviour. The improvement on labour costs was analysed through the integration of RFID technologies.

For a representative estimation of RFID impact on the customer indicators, we decided to focus on the Direct Operating Cost (DOC). This indicator includes the DMC and other maintenance costs (maintenance labour at the customer side, fuel and lubricants). As an example, it includes the man hours involved at the operator side. Even if the OEM or the maintenance shop performs the maintenance task, the operator also realises maintenance actions (part installation or part removal). These maintenance actions are considered into the DOC. Moreover, it concerns the fuel expenses and the needed lubricants.

The customer audit highlighted areas of improvement in their processes linked to RFID integration..

For Case 2 (overhaul), the simulations show earnings of 2.8 % of gain on the DMC. The DOC decreases by 5.8%. Very good results are achieved on several specific parts (e.g. the Main Gear Box). The study led on these particular parts cannot be given here for confidentiality reasons. The percentages reflect an average value of all parts followed in the aircraft or with a low Meant Time To Failure (MTTF).

CONCLUSIONS

OEM (Original Equipment Manufacturer) processes will be improved; customers must also take advantage from RFID. The work and results presented in this paper are therefore customer oriented. As RFID technologies need significant investment, it is the key to demonstrate the, Return-On-Investment.

Our study has shown that RFID technologies strongly impact maintenance processes. Our analysis considered all maintenance levels. The chosen cost indicators are the Direct Maintenance Cost (DMC) and the Direct Operating Cost (DOC). Both are impacted on man hours by RFID technologies. These indicators are a reference for both aircraft manufacturer and aircraft operator. Thus, we can expect economic improvements and competitive advantages.

In a future work, we intend to broaden our simulation models using adapted probabilistic laws. These laws should improve the accuracy of the boundaries of time intervals. Further studies will concentrate on new services supported by the introduction of RFID technologies on helicopters.

ACKNOWLEDGMENTS

This work has been partially financed by the ANRT (Association Nationale de la Recherche Technique) through the PhD n° 911/2008 with CIFRE funds and a cooperation contract between EUROCOPTER and ARMINES.

REFERENCES

- [1] K. Kang , K. Gue , D.R. Eaton. Cycle time reduction for naval aviation depots. Winter simulation Conference, Washington, United States, pp.907-914, 1998.
- [2] U. Sadananda, N. Srinivasan. A Simulation Model for Availability under Battlefield Situations. Simulation, Vol. 74, No. 6, pp. 332-339, 2000.
- [3] H.S. Balaban, R.T. Brigantic, S. A. Wright, A. F. Papatyi. A Simulation Approach to Estimating Aircraft Mission Capable Rates for the United States Air Force. Winter Simulation Conference, Orlando, United States, pp. 1035 - 1042, 2000.
- [4] K. Virtanen, T. Raivio. A simulation model for aircraft maintenance in an uncertain operational environment. 17th European Simulation Multiconference, Nottingham, England, pp. 456 - 461, 2003.
- [5] T.N. Cook, R.C. DiNicola. Modeling Combat Maintenance Operations. In Proceedings of the 1984 Annual Reliability and Maintainability Symposium, San Francisco, United States, pp. 390-395, 1984.
- [6] T. Raivio, E. Kuumola, V.A. Mattila, K. Virtanen, R.P. Hämäläinen. A simulation model for military aircraft maintenance and availability. European Simulation Multiconference, Prague, Czech Republic, pp. 190-194, 2001.
- [7] R.M.H. Knotts. Civil aircraft maintenance and support Fault diagnosis from a business perspective. Journal of Quality in Maintenance Engineering, Vol. 5, No. 4, pp.335 – 348, 1999.
- [8] H. Wu, Y. Liu, Y. Ding, J. Liu. Methods to reduce direct maintenance costs for commercial aircraft. Aircraft Engineering and Aerospace Technology. Vol. 76, No. 1, pp. 15-18, Feb. 2004.
- [9] W.H. Wen-Hsien Tsai, L. Kuob. Operating costs and capacity in the airline industry. Journal of Air Transport Management, Vol. 10, No. 4, pp. 269-275, July 2004.
- [10] P.A. Gearhart, R. Wuerz, A.R. Localio. Cost-effectiveness analysis of helicopter EMS for trauma patients. Annals of emergency medicine, October 1997.
- [11] N.W. Foster, H.D. Hunsaker. The effect of aircraft age and flying hours on maintenance costs. AFLC technical report N°82-099, June 1983.
- [12] ATA Spec 2000 Chapter 9.5 specifies a common, industry standard data format which can be written onto tags and which can be read by any another company along the aerospace value chain during the part's lifecycle.
- [13] B. Iung, E. Levrat, A. Crespo Marquez, H. Erbe. Conceptual framework for e-maintenance: Illustration by e-maintenance technologies and platforms. Annual Reviews in Control, Vol. 33, No. 2, pp. 220-229, December 2009.
- [14] C. Feuillebois, M. Glade, E. Pauly. Automatic Configuration-Tracking Apparatus, And a Method and a System for such Tracking. French Patent Application, Publication Number: FR 2.928.761, Publication Date: Sep. 18, 2009.
- [15] EASA Part M – Application and guidance information for approval of maintenance organisations. Easa.europa.eu (regimentations section).
- [16] Jeong K.-Y., Oh J.-H. Aerospace Maintenance Supply Chain Optimization via simulation, Wseas transactions on computers, Issue 4, Volume 2, October 2003.
- [17] T. Raivio, E. Kuumola, V.A. Mattila, K. Virtanen, R.P. Hämäläinen. A simulation model for military aircraft maintenance and availability. European Simulation Multiconference, pp. 190 – 194, Prague, June 2001.
- [18] C.G. Schaefer Jr, D.J. Haas. A simulation model to investigate the impact of health and usage monitoring systems (HUMS) on helicopter operations and maintenance. AHS International, 58th Annual Forum, Vol. I, pp. 785-797, Montreal, Canada, June 2002.
- [19] C. Jimenez, S. Dauzère-Pérès, C. Feuillebois, E. Pauly. Integration of RFID technologies for helicopter maintenance, Impacts on processes. Lambda Mu Congress, La Rochelle, France, October 2010.
- [20] C. Jimenez, S. Dauzère-Pérès, C. Feuillebois, E. Pauly. Integration of RFID Technologies in Helicopter Maintenance Processes. European Rotorcraft Forum, Paris, France, September 2010.
- [21] Military Standard, Definition of effectiveness terms for reliability and maintainability, Military Specifications and Standards, 12-Jun-1981.
- [22] D.J. Hurst. Operational availability modeling for risk and impact analysis. Annual reliability and maintainability symposium, 1995.
- [23] M. Glade. Modélisation des coûts de cycle de vie: prévision des coûts de maintenance et de fiabilité Application à l'aéronautique. PhD thesis, Ecole Centrale de Lyon, January 2005.
- [24] A.J. Cook, G. Tanner. Innovative Cooperative Actions of Research & Development in EUROCONTROL Programme CARE INO III Dynamic Cost Indexing: Aircraft maintenance – marginal delay costs. Technical report, Transport studies group, University of Westminster, 2008.