The Maximum Maintenance Mastery at Eurocopter

G. Poncelin [1], A. Lefebvre [1], P.L. Maisonneuve [1], M. Glade [2], J.P. Derain [3],

[1] Eurocopter TAST, Maintenance & diagnostic research
Aéroport Marseille Provence, 13725 Marignane CEDEX
e-mail: Guillaume.Poncelin@eurocopter.com
e-mail: Arnaud.Lefebvre@eurocopter.com
e-mail: Pierre-Loic.Maisonneuve@eurocopter.com

[2] Eurocopter TAST, Head of Research in Maintenance & Diagnostic
Aéroport Marseille Provence, 13725 Marignane CEDEX
e-mail: Mathieu.Glade@eurocopter.com

[3] Eurocopter TAST, Head of dep[t] Maintenance & Diagnostic
Aéroport Marseille Provence, 13725 Marignane CEDEX
e-mail: Jean-Pierre.Derain@eurocopter.com

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Abstract: In the helicopter industry, the breakdown of the life cycle costs is particular in the fact that on average, 35% of these costs are expended for the maintenance. This article describes the projects set up at Eurocopter to achieve three complementary goals, design for reliability, maintenance credit, and diagnosis, which have been identified as essential to perform the greatest impact on the DMC and to optimize the availability and the logistics of the helicopters, which is called Maximum Maintenance Mastery.

1 INTRODUCTION

In order to satisfy expectations of its customers, Eurocopter tries to reduce the maintenance costs responsible for most of the expenses of the customers during the helicopters life cycle. Five major fields of work are to be distinguished in order to achieve this goal:
- make the design reliable;
- anticipate the failures thanks to the diagnosis;
- improve maintainability;
- improve repair;
- Work on logistics.

With the reduction of the maintenance costs in mind, a product-oriented approach was developed.
In order to have a maximal impact on the product, an integrated approach including the reliable design of the aircraft, the failures anticipation through the prognosis and the maintainability control, has been developed. The concept of Maximum Mastery Maintenance (M3) is articulated around these three axes. Further more, it appears that the interactions between these skills are an important source of earnings in terms of maintenance costs.

The article will first introduce the impact of maintenance on the ownership cost of a helicopter, then the three axis will be described as well as their impacts on the diagnosis costs, finally the interaction between each part of the M3 concept will be presented to conclude on the sources of earnings obtained through a maintenance design integrated approach.

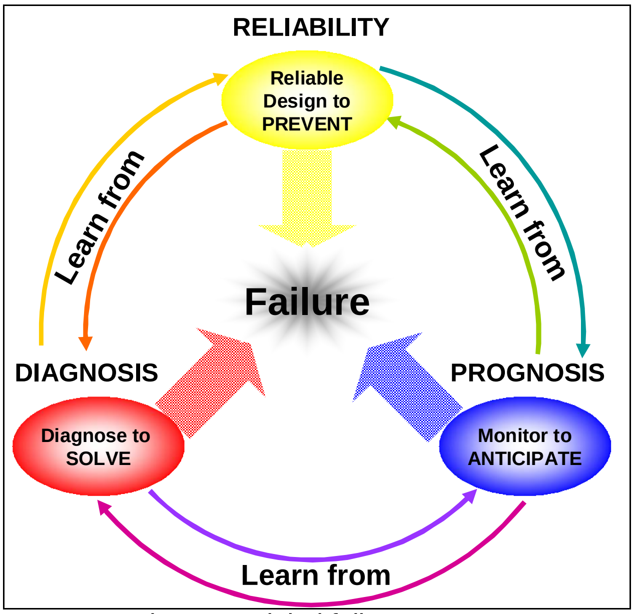

Figure 1: Global failure mastery

2 COMPETITIVENESS IMPROVEMENT

2.1 The aeronautic maintenance, an expensive activity.

In order to produce cheaper, large progresses have been realized with the development of many cost control methods in the most expensive sectors such as the R&D, the production or logistics. However to gain in competitiveness in the aeronautic field, controlling the costs to reduce the selling price cannot be regarded as sufficient. Indeed, insofar as this last accounts for approximately 25% of the costs that the customers will have to pay on the whole of the life cycle of their helicopters, the development and the installation in Eurocopter of new methods, tools and means to control the total ownership cost (TCO) becomes paramount. Figure 2 shows the distribution of this TCO. The costs of utilization and insurance being relatively incompressible from the point of view of the industrial, this figure shows the new stakes of the competitiveness of Eurocopter on an international level: the control of the direct maintenance costs (DMC), in responsible on average for approximately 35% of the Total Costs of Ownership.

2.2 The reduction of maintenance costs.

DMC breakdown

The DMC can be divided into two great parts which add up: the cost of scheduled maintenance and the cost of corrective maintenance. The simplified formula of the DMC can be written:

$$DMC = \frac{\text{Maintenance Cost}}{\text{Term}} + \frac{\text{Reparing Cost}}{\text{MTBUR}} \quad (1)$$

Parameters sensitivity analysis

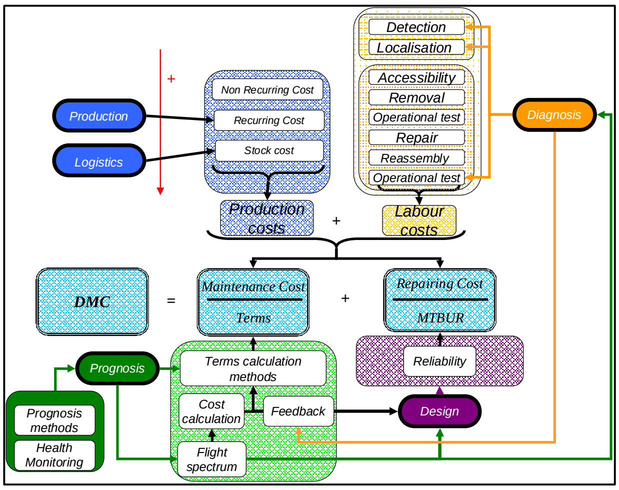

Figure 2: M3 impact on DMC

The cost of scheduled maintenance per flight hour is understood as the relationship between the maintenance costs divided by the period between two terms of maintenance.
The cost of corrective maintenance per flight hour is understood as the relationship between the maintenance costs divided by the period between two terms of non-scheduled maintenance tasks. (MTBUR). (See formula 1).
It is imperative to control the costs of scheduled maintenance, as well as the costs of corrective maintenance to control the DMC per flight hour.

- The control of the equipment reliability makes it possible to increase the frequency between two terms of corrective maintenance.
- The control of the prognosis makes it possible to recalculate and increase time between two terms of scheduled maintenance

The terms of scheduled maintenance are determined by calculation as of the design. Their optimization is carried out by using models which take into account severe flight spectrum of usage and economic choices (design to cost). The monitoring system recalculates these terms by using the real usage of the helicopter in order to best fit the torque (cost, terms). Thus, the prognosis allows to reduce the term and to optimize the maintenance costs.

The control of maintainability allow to reduce the costs closely related to a maintenance task by reducing the duration, by simplifying and decreasing the number of tools necessary for the good working order of the helicopter.
By maintainability we mean the quality of a product that is easy to maintain. A maintenance task can be broken up into two phases, a diagnosis phase, identification of the origin of the failure and a repair phase. The design for repair is the object of studies at Eurocopter that complement the M3 concept.

This article will thus attempt to control the reliability, the prognosis, and the diagnosis in order to master the DMC.

Assessment of the above mentioned activities: reliability, prognosis, diagnosis = M3
The research and development activities in maintenance at Eurocopter allowed the implementation of a complete system of management of the maintenance costs that integrate the exhaustiveness of the profit levers. The controlled reliability, the active prognosis, the successful diagnosis as well as their optimal interactions make it possible to maximize the control of the maintenance costs.

3 MAINTENANCE MASTERY RESEARCH AT EUROCOPTER.

3.1 Reliability

Today, the estimated studies of reliability carried out by the industrials during the systems design are done with three objectives: to prove safety, to ensure the availability and to predict the maintenance costs of the equipments. To reduce these future maintenance costs and to target the objectives of DMC increasingly more difficult to reach, the actions usually performed to increase reliability such as the identification and the suppression of the first modes of failures or the requests of redesign to the equipment suppliers are not enough any more. Other methods, tools must be explored, worked out and set up to control the reliability of the equipment from the design phase and on all the products life cycle [1]. The “design for reliability” is a method which applies from the design phase and requires to know to anticipate the consequences of the design choices on the final reliability of the systems. Consequently, it is necessary to identify on the one hand the types of systems which must be treated separately since they require the use of specific tools to carry out reliability forecasts. On the other hand, it is necessary to identify the parameters of the design choices which influence the reliability of these systems and how they must be grouped.

3.1.1 Direction of actions to perform

3.1.1.1 Segmentation by type of system.

Figure 3 shows the distribution of the maintenance costs on a mid range helicopter. Thus, three types of subsystems can be identified for which actions of reliability control must be carried out: subsystems from the electronic field, subsystems from the mechanical field , as well as subsystems which generally integrate several fields: hydroelectric, thermomechanical etc, which one will be grouped in subsystems known as “complex”.

3.1.1.2 Segmentation by influent element.

To control the reliability of the systems, the first stage consists in identifying its elements of influence to determine how to direct the actions to be carried out. Doing so is a question of using normalized tools for system reliability calculations. These tools are used to calculate the reliability of the systems using parameters that require to be quantified by the user and which will influence the result of it: the reliability. Thus, these tools enable to identify the parameters necessary for the reliability calculation of the electronic components and to classify them in three categories:

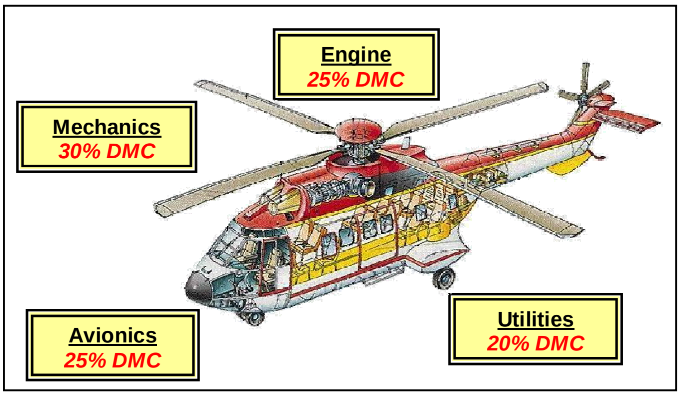

Figure 3 : DMC broke down by type of system

- The “System Internal Reliability” which depends on the design of each subsystem. It then contains the whole of the intrinsic parameters to the system that influence its robustness to a given environment (quality of the components, technology used, characteristic of the product…)

- The “System External Reliability” which depends on the design of the environment of the subsystems. It gathers the constraints belonging to the environment external to the system (environment thermal, mechanical, chemical and moisture as well as the accidental overloads that will affect the products).

- The “System Process Reliability” which comes under the procedural field. It represents the whole of the procedures set up by the actors of the systems during its life cycle and which affect its reliability.

Thus, the control of the equipment’s reliability requires the control of its robustness, its environment and its processes

3.1.2 Three levers of reliability optimization.

3.1.2.1 System Internal Reliability

The control of the products robustness must be done to a given environment. It is a question of identifying by the calculation or the study of the repairing reports, the elements of the subsystems the most fragile, and then the ones that require the most to be protected, reinforced or substituted. This layer is now and for years well mastered in industries and has been currently applied to Eurocopter and its suppliers.

3.1.2.2 System External Reliability

If the average reliability of an office computer is higher than 50.000 hours, the one of a similar equipment embedded on helicopter is divided approximately per 10. The reasons of such a reliability variation are the conditions of use, i.e. the constraints imposed by the external environment. It is then for the integrator to deal with the identification of the constraints from the environment that affect the reliability (thermics, vibratory, chemical, moisture) and to quantify their respective impact on reliability.

This will make it possible on the one hand to direct from the first phases of design, the design choices and in the other hand to launch projects of constraints reduction. The objective being the reduction of the maintenance costs to the maximum by determining the best compromise between the different other important parameters such as the costs and the weight. These projects of engineering reliability are currently mature and set up for the design and the redesign of the helicopters thanks to the development of the FIDES tool. Insofar as this tool makes it possible to realize in design the reliability forecasts taking into account all the influential parameters, it makes possible the profitability evaluation of the projects of environment control and provides the arguments necessary and sufficient for the decision-making process which optimizes triptych Costs / Weight / DMC.[2]

3.1.2.3 System Process Reliability

When the system internal and external reliability is under control the last factor to master to have a total and complete control of reliability is the evaluation of the processes set up by Eurocopter on the whole life cycle of the products. Indeed, because of the improvement of the two other levers, the share of the failures generated by the quality and the technical control of the reliability in the life cycle of the product become dominating, and as shown in the figure 4, it is evaluated today responsible for the reliability of the equipment at 80% [3]. This evaluation and the improvements which result from it were made possible at Eurocopter by the use of the of “reliability audit guide” formalized within the framework of the work completed in FIDES project now recognized as standard UTEC 80-811.

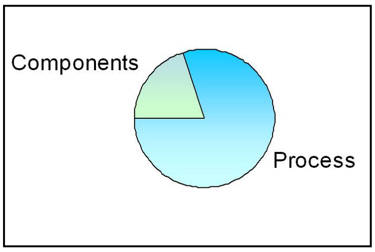

Figure 4: Proportion of failures generated by the activities related to the process

3.2 Prognosis

3.2.1 Aircraft health monitoring

The prognosis is based on a global monitoring tool allowing a thorough and reliable knowledge of the helicopter. It consists in permanently monitoring the components health by determining the deterioration level of the critical mechanical elements (engine, transmission) and the avionics. Thanks to a perfect knowledge of the real usage of the helicopter (engine speed, spectrum of flight, speeding…) and thanks to the mastery of the degradations modes of the helicopter elements. This tool makes it possible to improve safety in flight by detection of a damage of critical element (before breakdown) as soon as possible in order to optimize the maintenance tasks and to reduce these costs.

3.2.2 Types of monitored parameters:

The parameters monitored by the on-board system of monitoring are classified in three categories:

Health parameters: they allow a detection of an abnormal functioning. The main parameter is the vibratory spectrum of the machine elements. It is generally calibrated by alarm thresholds or, health indicators that are continuously calculated and which indicate the deterioration level of the monitored element.

Usage parameters: they represent the conditions of use of the helicopter or the monitored part. They group together the temperatures, the pressures…. They make it possible to have a history of the constraints exerted on the helicopter elements. They also result from additives analysis such as oil, grease, exhaust gas, etc which make it possible to detect a state of degradation.

Flight parameters: they result from a flight recorder which records the main external parameters, climatic parameters, flight altitude and flight position… making it possible to know the real flight spectrum of the helicopter.

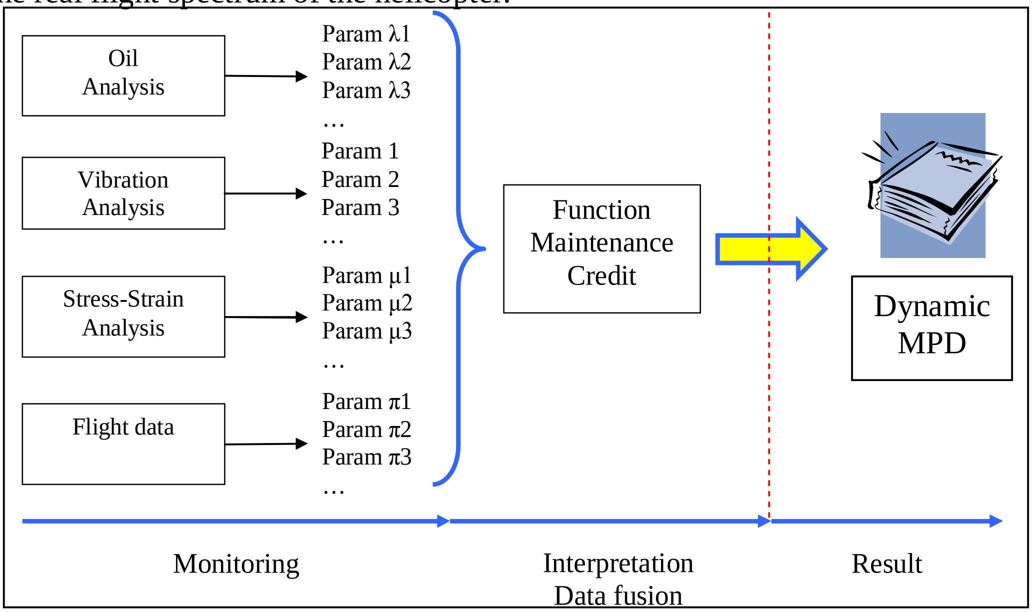

Figure 5: Maintenance Credit

3.2.3 Objectives to be reached:

The health prognosis of the helicopter elements makes it possible to set up the concept of maintenance credit. It consists in giving to the user an additional term to the spare parts when its aircraft comes at the end of its life; this if there are no excessive damages requiring a removal. The Maintenance planning Program Documentation (MPD) becomes flexible and dynamic. It fits the real usage of the aircraft and the intrinsic and extrinsic conditions undergone by the helicopter [4].

The Health prognosis directly impacts on the maintenance costs and more particularly on the DMC by:

- Increasing the term of the parts.
- Increasing the availability of the helicopter: failure anticipation and flight clearance if the basic terms calculated at the time of the design are exceeded.

- Improving the stock management by reducing its number of parts: the order is placed when the failure is predicted.

The prognosis has thus a major impact on the quality of the Eurocopter helicopters thanks to the DMC reduction but also by reducing and doing away with maintenance tasks where the monitoring system replaces the checking that have been carried out by the pilots and the maintenance operators. The system must have a sufficient level of certification to authorise its use in maintenance [5] [6].

3.2.4 The function of maintenance credit, a data fusion:

The decision-making and the calculation of a new expiry date go through the fusion of the recorded data and the correlation of the indicators generated in the various categories. This data interpretation allows the application of the function of maintenance credit which generates information delivered with the maintenance operator. It allows on a data correlation system making it possible to follow the degradation of an element. The inputs of the on-board system (figure 5), are treated by tools, as neural networks and models of residual reliability calculation allowing an interpretation of the recorded data with the aim of calculating the term in real time (Time Between Overhaul, Service Life Limit…)

3.2.5 Applications

Here are two examples illustrating the concept of maintenance credit.

- Oil Analysis:

The monitoring system integrates a module allowing oil analysis [7], using on-board spectrography, fragment analysis, etc to control the various modes of deterioration like the fretting, spline wear, bearings, etc. This analysis is combined with the monitoring of the oil parameters as its flow for the height of oil film in the bearings, its temperature, its age which make it possible to quantify, by wear models, the degradation undergone by the dynamic machine elements [8].

- Damaging of Flight Spectrum:

As the detection of the usage involves an abnormal degradation of the helicopter elements, it is necessary to determine the remaining life potential of the composed elements of the helicopter. For that purpose, a data base allows to link up a flight spectrum, usage and health data with incidents and maintenance operation which occurred on the aircraft (experience feedback). The methods of data fusion (Fuzzy fusion) [9], the methods of neural networks [10], and the wear models are used to determine the deterioration level and thus the potential of remaining life.

Conclusion:

The on-board health monitoring system on the Eurocopter helicopters is composed of several modules all closely connected in order to follow, with all the necessary reliability, the health or the deterioration of the helicopter.

3.3 Diagnostic

3.3.1 Objective and problematic

Diagnosis allows the automatic monitoring of the aircraft condition. Two aspects for the diagnosis are to be distinguished: the operational part for the pilot to inform him about the health of the aircraft, and the ground part, where information is given to the maintenance team to perform the reparation of the helicopter.

Diagnosis is generated at the level system by the compilation of the various failure information generated at the level equipment by the integrated test. When a failure appears on equipment, it is detected by one or several integrated tests, and generate one or several failure messages. The diagnosis is based on these failure messages, as well as on several other additional data to determine with a maximum of precision what the origin of the failure is.

The main question to which the diagnosis must answer is: How can we improve the safety through the diagnosis without degrading the operability of the aircraft and impacting the maintenance costs negatively?

Two problems come to degrade the operability of the helicopter by impacting in a negative way the performances of the diagnosis as presented on figure 6.

These problems are the false alarms and the localisation ambiguities of the failures.

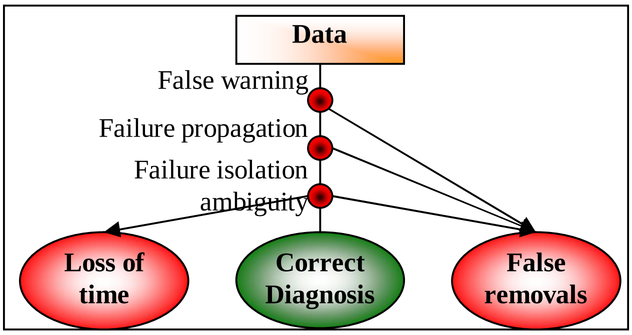

Figure 6: Diagnosis problematic

The mastery of maintenance cost is partly performed by the control of these two problematic that affect the efficiency of the diagnosis. Indeed them false alarm decrease the average time between two unscheduled interventions and are responsible for false removals causing an useless increase of the DMC.

Localisations ambiguities also affect the diagnosis by increasing the necessary time to isolate a failure; these ambiguities are also a source of useless unscheduled maintenance operations.

A good diagnosis makes it possible to ensure an effective maintenance while decreasing at the maximum the influence of the harmful parameters on the DMC.

<u>Innovations axes</u>

Two approaches can be considered to answer the various problems generated by the diagnosis.

- The first approach focuses on the equipment level, by improving the BIT definition, by laying out the points of tests in a more effective way, etc…
- The second approach focuses at system level on the definition of a diagnosis algorithm by taking into account all necessary information coming from the equipment tests and from additional data to generate the diagnosis.

The integration of the various equipments in avionics involves an increasing complexity of the problems that require a system level treatment. Rather than oppose these two approaches, the Eurocopter suggested diagnosis federates the completed work at the equipment level in a diagnosis algorithm that is defined at the system level.

<u>The diagnosis algorithm at the system level</u>

The diagnosis algorithm is based on several input data which are:

- Failure messages coming from the BIT: with their date of appearance and possibly of disappearance.
- The flight period during which the failure message has been recorded
- Additional data coming from the sensors.
- Helicopter configuration
- Reliability data of the various on-board equipments

The data processing is carried out by a diagnosis organized in several parts (see figure 7):

- The filtration of failure messages according to their number of occurrences, their duration, the flight period during which they appeared, etc. in order to determine if certain messages are false alarms.
- A correlation between the failure messages based on the failure dynamic, the appearance time as well as on the system architecture.
- A logic processing is performed to isolate the failure by basing itself on the dynamic fault trees. The logical correlation is set up with complementary parameters in order to determine the faulty element and to reduce the ambiguities of failures localisation. [11]

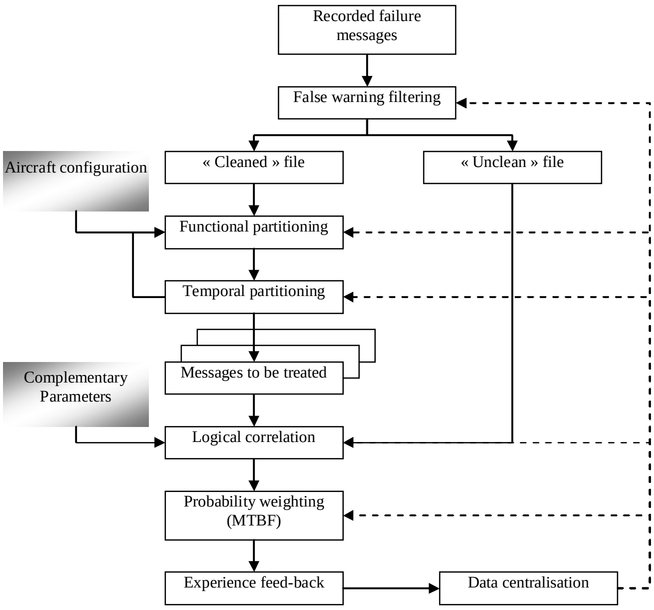

Figure 7: Diagnosis functional diagram

In the case of fault isolation ambiguity, we lean on the information resulting from reliability calculations in order to balance the relative probabilities of failure between the various equipments.
The faulty suspected element is then pointed out to the maintenance operator. The diagnosis is presented under the form of a machine diagram where the faulty suspected elements are displayed; the link between the failures and the work sheet describing maintenance operations is realised. Moreover the diagnosis is conceived in a way that he can be updated according to the experience feedback; this allows improving the capacity to eliminate the false alarms during the life of the helicopter while improving the failure localisations.

The robust diagnosis generates relevant information for the pilot as well as for the maintenance. Thus, it fulfilled its function to improve safety of the flights and to maximize the operability of the aircraft by reducing the maintenance costs.

4 *INNER CONCEPT SYNERGY*

4.1 Shared resources and results

The reliability, the prognosis and the diagnosis are three closely connected activities. They are completely interdependent because of the usage of common resources such as the spectra of flights, etc… The interdependence also results in the fact that some of the essential data are exchanged between the various activities, making it possible to achieve a common goal, the reduction of the maintenance costs (see figure 8).

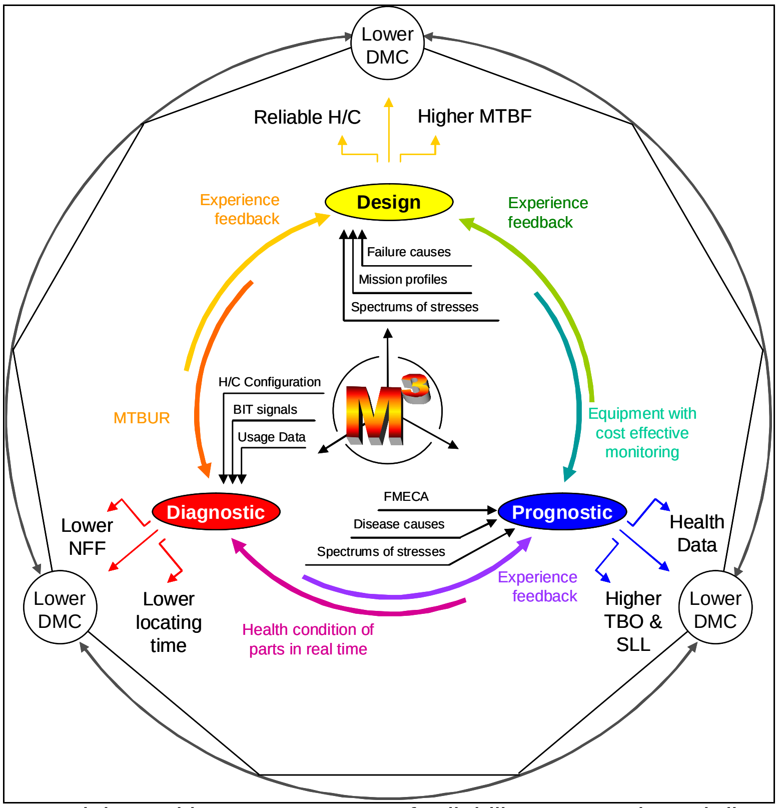

Figure 8: Links and impacts on DMC of reliability, prognosis and diagnosis

4.1.1 Reliability

The activities of reliability engineering realized from the design phase of the helicopters require technical and financial data, almost not available at such an early phase. Moreover, the figures resulting from the use of reliability prediction tools are associated to an error margin difficult to quantify and on which the decision makers still hesitate to base their reflexion. Thus, most of these projects will consist in working by analogy on helicopters in exploitation starting from data on operating equipment and for which data have been measured and validated. These data to exist need on the one hand the "prognostic" work package which provides data such as the measured mission profiles or the degradation level of the parts observed under real conditions of use. In addition, these data need the diagnosis work package which consists in providing field return data of equipment reliability, of failure modes and of breakdown causes, necessary to a reliable design of the helicopters.

4.1.2 Maintenance credit:

The choice of the elements to be monitored is directed by the analysis of the reliability performed during the design phase. The most potentially faulty elements that have a high maintenance cost and thus a weak expiry dates, have degradation modes controlled by the monitoring module. It is important to point out that the return on investment for the development costs of the monitoring tool achieved rapidly since they are judiciously chosen by the reliability analysis. The maintenance credit thus acts as complement of the reliability work of the helicopter elements, while providing an experience feedback on calculations that are carried out in design phase (spectrum of real flight …). Once the objectives of the monitoring tool have been chosen, the diagnosis will provide confidence necessary to have in the integrity of the system to allow its certification. The correct implementation of the means of measurements, calculations, etc... lean on a tool for powerful diagnosis. The measurements and the calculations performed in real time are validated by this tool. It also supplies the diagnosis in maintenance data allowing to adjust the dynamic expiry dates. There is thus a data exchange between the system of fault finding and the system of vital diagnosis of failure to reach a high technological level making it possible the installation of the functions of maintenance credit.

4.1.3 Diagnosis

The reliable design aims at decreasing the rate of failure occurrences by maximizing the reliability of the parts; the prognosis aims at anticipating the failures which are able to appear on equipment; the diagnosis aims at isolating a failure as fast as possible when it appears.
The diagnosis determines which the faulty element is. To carry out this failure localisation, the diagnosis is based on the messages coming from the internal tests as well as on additional information (see figure 7).
The data coming from the reliability and the parameters monitored by the diagnosis as well as interpretation of degradation are used to generate the diagnosis.

4.1.3.1 The integration of the reliability data in the diagnosis algorithm:

The reliability data is integrated into the algorithm when a localisation ambiguity between two pieces of equipment is detected. The mean times between failures of the various equipment or the elements that are suspected to be failed, are used as complementary data to propose a probability of failure occurrence.
A linear regression between the failure rates of the various elements is performed in order to estimate a probability of failure for each element. This value is balanced by the calculation of degradation carried out by the prognosis.

4.1.3.2 The integration of the prognosis in the diagnosis algorithm:

The prognosis function makes it possible to determine which the health of the equipment is. This information is used to balance the estimated probability of failure obtained with the reliability data calculation presented previously. Thanks to this double calculation, it is possible to give a probability of occurrence for a failure.
Information coming from the flights spectrum, generated thanks to the prognosis acquisition module, is used to distinguish between real failures of false alarms.

4.2 Mutual improvement

The M3 approach presents techniques that have been implemented in order to maximize the costs profits induced by the maintenance operations. Design for reliability, prognosis, diagnosis produces a global impact by decreasing the number of failures, by anticipating them, and by precisely locating them when they occur.
The complementarity of the M3 approach not only results in an individual profit for each one of the parts but also in cross profits resulting from the relations between the various parts.
Thus the improvement of the reliability evaluation allows to define better the critical parts to monitor; it is also an entry of the diagnosis algorithm by improving the statistical evaluation of the faulty parts.
The follow-up of the remaining life of the helicopter by the prognosis allows a reliability experience feedback, opportunity for design improvement. Remaining life of the parts as well as the measured profiles of mission are the data input of the diagnosis algorithm.
The diagnosis improvement allows an experience feedback used to improve the reliability in the design. This experience feedback is used by the prognosis in order to update the calculation of the thresholds before failure, according to the maintenance operation that have been done.
Thus the improvement of a field allows the cross-improvement of the other M3 fields, which has an interest to improve in a total way the control of the DMC.

5 CONCLUSION

The deployment of the M3 concept is gradually implemented on the Eurocopter helicopters until reaching a total maturity level and a maximum deployment within 5 years. The cost profits study shows that the DMC of the various helicopters could be reduced from 15 to 20%. To conclude, the making up entities of “M3” concept allow to impact all the parameters that act upon the DMC. The control of reliability enables to propose design solutions which optimize the MTBUR of the helicopter elements according to the weight, price and maintenance costs triptych. It also permits to know the equipment that are interesting to be monitored by the prognosis. The prognosis is based on the monitoring of the helicopter equipment; it records the real usage of the aircraft to estimate the degradation level of the parts.

This then allow to recalculate in real time the life span of maintenance and to update the maintenance planning. The extend time between two maintenance actions may be extended if calculated degradation is lower than degradation initially envisaged. Then when the failure occurs, the diagnosis decreases the time of fault isolation and avoids the maintenance operator carrying out himself the localisation while following heavy procedures. This reduces the time of realisation of the maintenance task and increases the aircraft availability. The diagnosis aims also at removing the overcosts, the workforce and the test costs that are involved by false removals.

The M3 approach of maintenance impact the major phase of the fault management, it means that we limit the risk of failure, we monitor the failure mode and anticipate the degradation and we propose tools and method to diagnose easily the faulty part. Thus in this presentation, we show that the next step is to go through logistic support in direct link with the failure management: The stock and spares management by the knowledge of the fleet usage, the logistic integrated means and the web mastery of failure.

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