FINAL SUMMARY REPORT OF THE HUMAN FACTORS IN AERONAUTICAL MAINTENANCE STUDY

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Revision	Date	Pages modified	Observations
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A	19/11/01	Pages 6, 7	Introduction and Frame of analysis
		Page 11	§3.1 : « the disappearance of the close supervision technique… »
		Pages 11 à 15	§3.2,, §3.4 : the highlighting of organisational changes (bullet points before / after)
		Page 15	§4. : paragraph and figure of liaison with §3
B	21/10/02	Page 14	§3.4. : Figure 6 : table of demands of traceability according to type of task.
		Page 15	§3.4. : “establishing quotations for clients.”
		Page 16 :	§ 4. : “those supervisors come from the work shops.”
		Page 18	§4.1. : co-jointly worker / controller (case T_d).”
C	05/11/02	Various pages	Comments by S. Deharvengt and S. Baker

GLOSSARY

AMM	Aircraft Maintenance Manual
ARA	Approval to the Re-opening of the Aircraft
ATA	Aircraft Transport Association
EIR	Electronic, cockpit Instruments and Radio
GPWS	Ground Proximity Warning System
JAR	Joint Aviation Requirement
MM	Maintenance Manuel –MM
MOM	Maintenance Organisation Manual
MO	Maintenance Organisation
TCAS	Traffic Alert and Collision-Avoidance System

SUMMARY

1. INTRODUCTION

This document represents EURESPACE's response to a request made by SFACT to carry out a study investigating the Human Factors involved in aeronautical maintenance.

This work concerning aeronautical maintenance falls within the domain of Human Factor studies carried out by the follow-up group DGAC-SFACT.

This study, originally entrusted by the SFACT to the EURISYS CONSULTANTS group, concerns the impact of the introduction of new-generation aircraft on aeronautical maintenance.

The EURESPACE organisation was consulted in January 2001 and requested to perform a complementary study concerning the Human Factors aspects of operator activity. Such investigation concerns the aircraft, as well as the organisation of competencies and functions within the different types of maintenance workshops.

SFACT require a complementary investigation studying the impact of evolutions occurring within the domain of aeronautical maintenance on the reliability of aircraft interventions.

Such evolutions concern:

- the transition from a logic of expertise to one of cost optimisation,
- the arrival of new technologies for on board systems,
- the evolution of the documentation regulating aircraft maintenance interventions.

To respond to this demand, EURESPACE set up a methodology of experience feedback , based on the direct involvement of the Maintenance Organisations (MO for the rest of the document). EURESPACE made contact with various organisations, some of such contacts being successful; notably those with organisations integrated or previously integrated in airline companies.

In an anonymous manner, EURESPACE performed :

- A series of interviews with the supervision personnel of the OM. We worked with representatives of the management , of quality assurance, of production and of the workshops.
- Observations of aircraft interventions. We took account of the current aircraft maintenance yards in the different organisations, relying on the availability offered to us by the organisations contacted.

We made contact with organisations at the beginning of 2001 and were able to meet the MO organisations at the end of the second semester.

We took advantage of data that had been previously collected during the first phase of the study, throughout 1999, to provide us with a background history, and therefore, to reveal certain evolutions occurring within the organisation of the OM.

This document presents the following results:

- Data related to the different steps of the maintenance process. Several annexes presented at the end of the document illustrate these analysed situations.

- An analysis of maintenance activity from the front-line operator's point of view. The front-line operator is the one performing the aircraft interventions. Indeed, this level of analysis is considered to be crucial for dealing with the question of the reliability and/or fragility of aeronautical maintenance activities.
- Recommendations drawn from the analysis of difficulties observed concerning the front-line operators.

2. FRAME OF ANALYSIS

The observations carried out on site demonstrate a very large variability in the classes of situations encountered in aeronautical maintenance (even planned visits). Because of a variety of different factors, it is not possible to determine a typical scenario of maintenance tasks. Those factors are the variations linked to the targeted equipment, the aircraft context, the composition of working teams or the type of planned service visit.

However, these observations enable us to form a general understanding of the different factors influencing the maintenance process within an MO (Ref. annexe figure 1).

To begin with, five important steps structure the maintenance process:

1. The planning of the maintenance yard,
2. The preparation of interventions,
3. The performing of interventions on aircraft,
4. The control of the result of interventions,
5. The traceability of the actions performed during interventions.

These steps, closely interdependent, are themselves affected by numerous external factors related to the global context surrounding an OM:

1. The evolution of the economic context, which constrains, more and more, the organisations within a logic of cost optimisation.
2. The technological evolution linked to the introduction of the new technologies for on board systems. New types of expertise need to be developed accordingly. Also, practical experience linked to the actual performance of tasks on an aircraft need to be modified.
3. The evolution of the regulations because of European and international harmonisation, which affects the internal organisation of the MO and the conditions for performing interventions.

The following figure illustrates the guiding outline of the study proposed by EURESPACE:

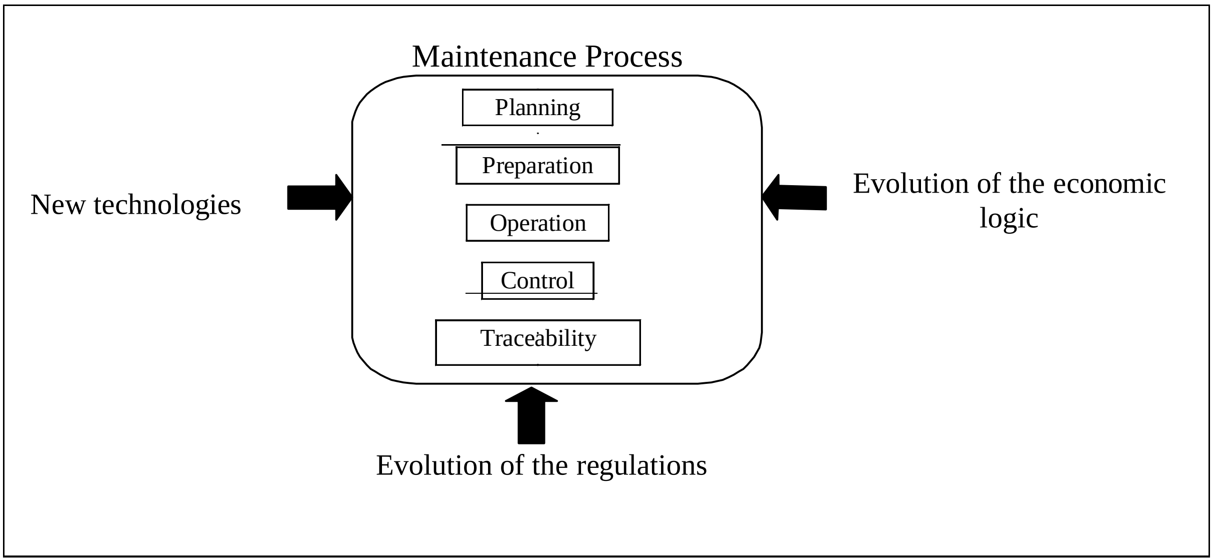


Figure 1: guiding diagram of the study

The objective of this document is to identify, among the modifications that seem to have appeared "due to circumstance and with limited effect", those which must be related to the evolutions of the global system in order to appreciate the long-term impact on the maintenance performance. To do so, our analysis is performed in two steps:

- In chapter 3, we describe the evolutions observed during the different phases of the maintenance process: the planning and the preparation of the work cards, the control and the traceability of the actions performed throughout the aircraft interventions.
- In chapter 4, we analyse the impact of these evolutions on the front-line operators' performance. We examine the difficulties related to the use of work cards and manufacturer documentation, as well as to the intervention on new technologies of on board systems.
- Chapter 5 assembles and presents the recommendations that can be made on the basis of the preceding analyses.
- Chapter 6 presents the conclusions drawn in terms of supplementary axes of investigation in order to, on the one hand, reinforce the validity of the results obtained, and on the other hand, to validate the durability of the control of the system described.

3. THE DATA : THE ORGANISATIONAL EVOLUTIONS OF THE OM

The efficacy of front-line operator activity depends essentially on the planning of the maintenance yard and the quality of preparation of tasks to be performed.

The level of efficacy achieved depends on conditions of maintaining control and on the traceability of performance.

Now, we will describe the principal evolutions of this process.

3.1. THE PLANNING OF MAINTENANCE YARDS

The running of programmed visits (small and large visits) requires the organisation of several hundred interventions in sequence. This planning constitutes « the red line » of running anticipated tasks, and is performed in order to synchronise the various necessary resources (supplying, mobilising the different disciplines, organising the intervention of external organisations…).

This activity of anticipation, which enables one to develop a planning strategy, occurs before the maintenance yards are started. It is the role of the planning authority to put such activity in place.

The planning originates from a logic that is purely technical, and a forward-looking programme of resource availability.

As the maintenance yard is started, the planning must be « in co-ordination » with the reality of the state of the aircraft to be worked on. Subsequently, several events may modify the running of the pre-planned interventions (lack of personnel, technical difficulties, non-anticipated interventions, lack of supply). Such events may therefore create a time lag between the progress of work as planned and the real advance on the line.

In order to achieve an optimal level of efficacy in the maintenance process, the planning must be continuously readjusted according to the interventions. Therefore, as the service visit advances, this « theoretical » planning needs to be « readjusted » according to the reality of the aircraft context[1] in order to reschedule pre-planned interventions.

Support for this readjustment of planning is provided by information recorded during the observation of front-line operator activity, that is to say the daily account of accomplished actions and available resources.

The interviews carried out on site revealed an important evolution in the process of refining the planning process in accordance with the evolution of the aircraft context.

- Previously, the launching of interventions, organised by the planning authority, was transmitted by technical proximity supervisors , specialised by technical domain (structure – cabin – equipment*). This supervision involved the receiving and storing of work cards as work advanced, and the distribution of tasks to the appropriate worker(s) according to several criteria:

[1] Aeroplane context: state of electrical and hydraulic supplies, for example.

- His knowledge of available human and technical resources,
- His knowledge of the aircraft context and the state of tasks in operation,
- His knowledge of the technical domain,
- His interaction with the other technical domains.

This technical proximity supervisor monitored the progress of work in collaboration with the workers by observing the evolution of cards, delaying them when they were suspended, and by orientating technically the interventions when encountering problems.

In this context, the technical proximity supervisor played a regulating role between the theoretical planning and its adjustment in the real situation.

Its role in the organisation of work can be represented in the following way:

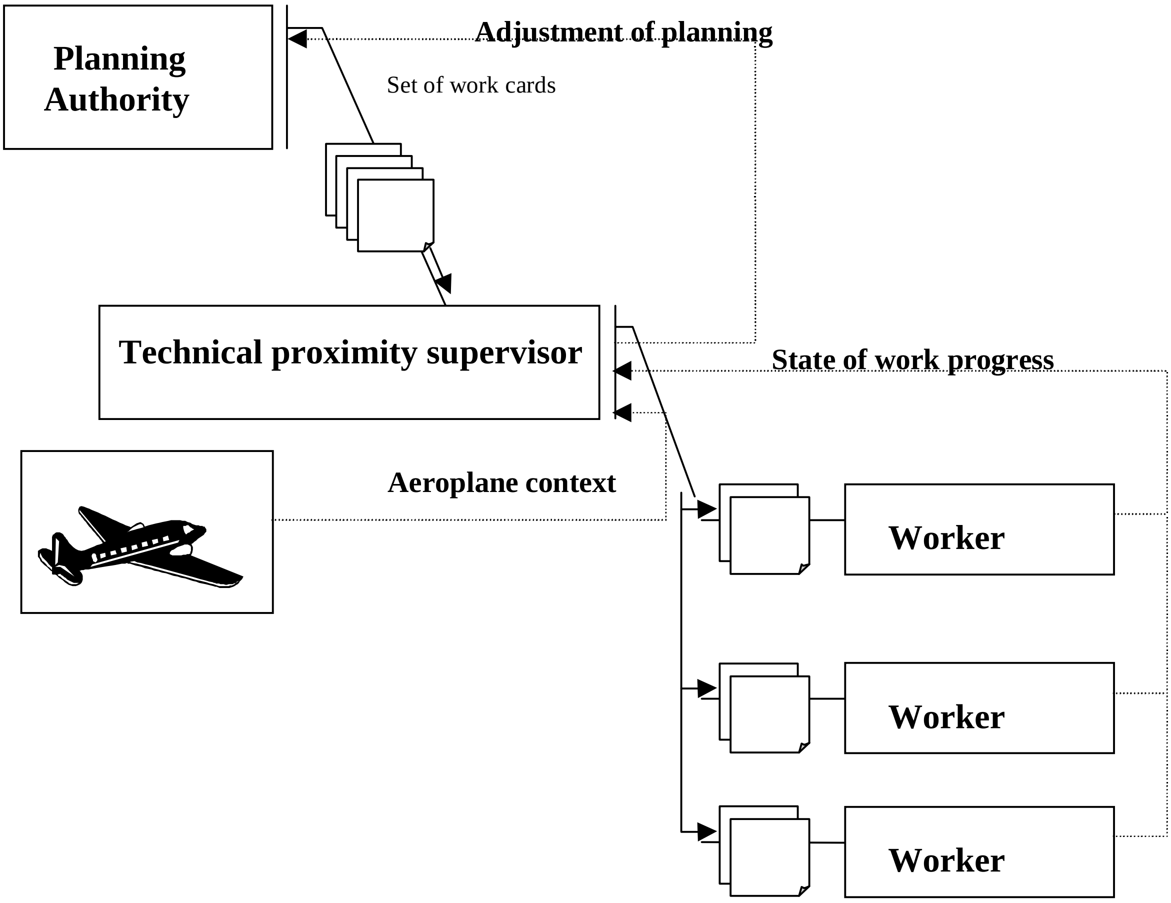


Figure 2: the role of the technical proximity supervisor in the adjustment of planning.

We can note the two successive levels of iteration, which enables one to take into account the real time of the aircraft context:

- On the one hand, iteration between the workers and the supervisor
- On the other hand, iteration between the supervisor and the planning authority.

- Today, the role of the team supervisor or foreman has evolved towards one of « administrative » management of paperwork linked to the organisation and the traceability of interventions.

This evolution leads to « the disappearance » of the interface role of the team supervisor between the planning and the front-line operator.

The following organisational plan is used at present:

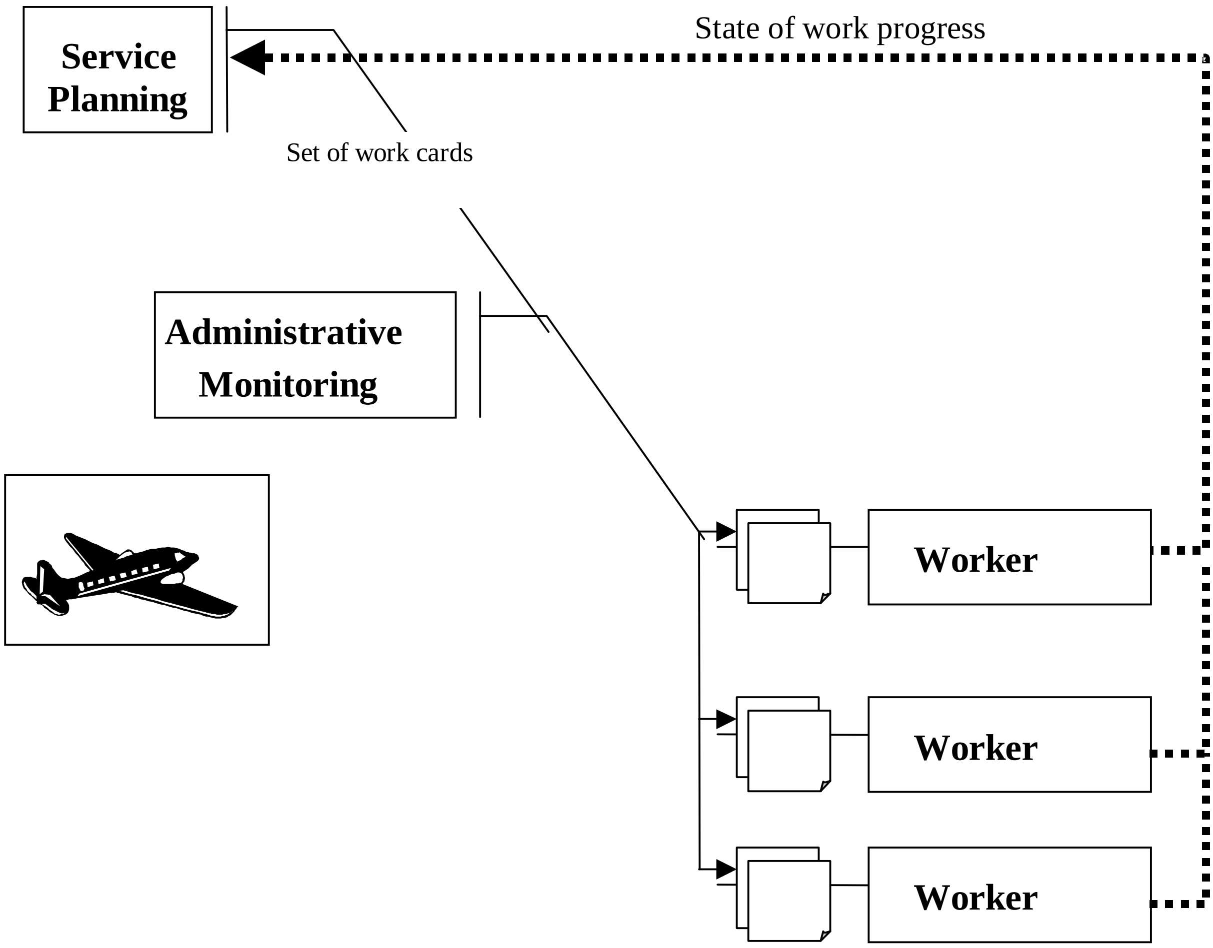


Figure 3: the role of the administrative proximity supervisor in the monitoring of work progress.

One issue is the direct iteration between the workers and the planning. Another is the lack of formalisation of the consideration of aircraft context. For example, we observe that the close preparation of tasks (local technical office, activities of « preparation ») is lost in order to make way for more centralised structures (eg.: in-house design office, manufacturer or external).

This disappearance of the technical proximity supervisor , that introduced a reinforcement of the administrative management of the maintenance yard, can be traced back to the willingness to establish improved economic control of the organisation of maintenance yards, in the present industrial context. It is also linked to the regulatory demand for a formalisation of the traceability of the interventions.

This evolution relies on the use of work cards, as representing procedures defining the conditions of aircraft interventions, as well as the resources (time, human and technical) to be anticipated.

This new organisation has several consequences on operator activity:

- Due to the shift organisation of work, each employee has a partial view of the running context concerning the state of the plane and the interventions in operation. Task performance may take the form of a preliminary search for information concerning the performance conditions affecting the current situation.
- The prescribed tasks can be out of sync with the aircraft context. Therefore, it can be practically impossible for the operators to accomplish them (Ref. annexe 2: the context of the intervention on the smoke detector in the rear cargo compartment, is modified following the advance of the intervention on the TCAS system).
- There is no direct interface between the operators and the planning, which means that planning cannot take account of updated information regarding the state of work progress.

Therefore, from the work organisation point of view, such organisation leads to a divergence between the two following processes:

- a « formal » process describing the planning of interventions,
- a « real » process linked to the effective constraints encountered on the ground.

The divergence between these processes and the lack of interface that could serve to « synchronise » them places the front-line operator in a situation where he is required to 1) intervene in situations different from those anticipated, and to 2) evaluate the necessity of launching the anticipated interventions.

➢ ***The analyses presented in chapter 4 focus on the regulating methods used by the front-line operators, and on the difficulties encountered, taking into account the present evolutions and those to come in the organisation of the OM.***

3.2. THE PREPARATION OF INTERVENTIONS

The preparation of interventions leads to the writing of work cards.

The writing of work cards is under the responsibility of the OM.

The work cards play a central role in the organisation of operator aircraft activity. Several functions are associated with work cards:

- Instructions regarding tasks to be accomplished and their associated conditions (competencies used, system targeted, required aircraft context…), based on the manufacturer recommendations presented in the « Aircraft Maintenance Manual » document (AMM throughout the rest of the document).

- Work assistance in terms of process method to be adopted, drawings and equipment references…. In this sense, the cards represent for the operator a means of obtaining assistance in his work, reminding him of the actions that he must perform, the information that he must consult, and the resources that he must procure.
- Support for traceability, enabling a follow-up of interventions and the persons involved. At the moment where the day's work cards are returned, signatures for each task (trigrams) are verified.

- Previously and notably for the MO benefiting from concrete experience, the work cards were designed and written by the technical office, which was also responsible for the follow-up of aircraft maintenance folders. The work cards corresponded to maintenance instructions, in parallel with the knowledge of real operational conditions. Regarding the function of work assistance, the content of information was issued from databases belonging to the organisation and concerned work assistance for operators.
- Today, due to the externalisation of maintenance services, the work cards are designed according to the function of the aircraft maintenance program specified in the client specifications. Before the maintenance yard phase, they are delivered by the planning authority and technically documented according to the AMM task references identified in the industrial market. According to his need, the operator must consult or print out the detail of operator methods contained within his tasks. Furthermore, the cards can be written under a different format, for a particular type of aeroplane, manufacturer or operator. In any of these cases, a front page specific to the MO is published. This page includes typically, information concerning the number and speciality of the operators involved, the anticipated duration of the task, the references and the AMM description of the task, as well as a zone dedicated to the traceability. Annexe 3 presents an example of a work card, along with a structure type of the front page and the associated AMM documents. Annexe 4 illustrates the use of manufacturer information.

The direct use of manufacturer documentation presents several advantages for the services operating before the workshop phase:

- A reduction of cost of intervention preparation due to the cost-effectiveness of conceiving and developing a specific documentation.
- A « guarantee » of the exhaustive range and validity of technical information.
- The use of the manufacturer documentation system (management of versions, production of supports, navigation tools…).

➢ ***In chapter 4, we present certain difficulties related to the use of work supports (work cards and manufacturer documentation) and we present the different regulating methods used by the operators to overcome such difficulties.***

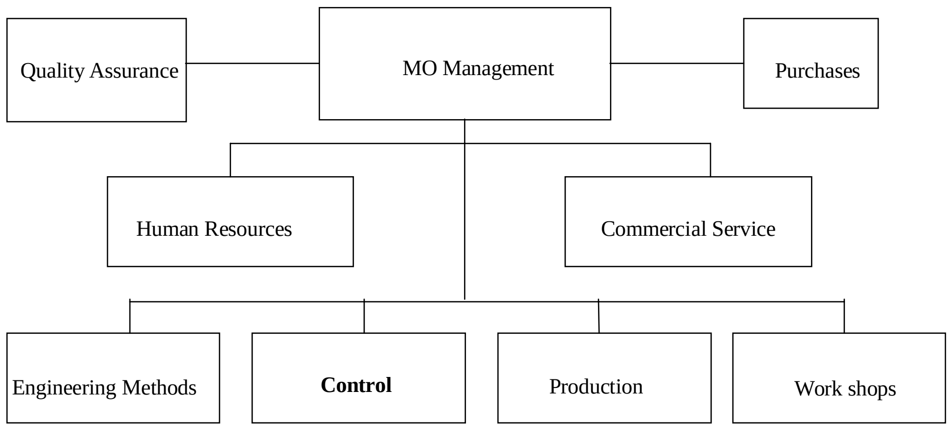
3.3. THE CONTROL

Control comprises the process of supervision and tracking of maintenance activity, which aims to ensure the final reliability of the systems. The exit from the maintenance process is indicated by the delivery of the Approval to the Re-opening of the Aircraft (ARA), document which guarantees the airworthiness level required for the aircraft.

This process is under the responsibility of the authorised controllers. Such controllers include those verifying and targeting the work accomplishment according to the aircraft requirements mentioned in the Maintenance Manual (MM), the constructive procedures prescribed in the Aircraft Maintenance Manual (AMM) and the operational work conditions governed by the regulations of the trust authority.

Depending on the MO, the « control » service may or may not be attached to the « production[2] » service.

- Traditionally, the control service is positioned externally to the production service:



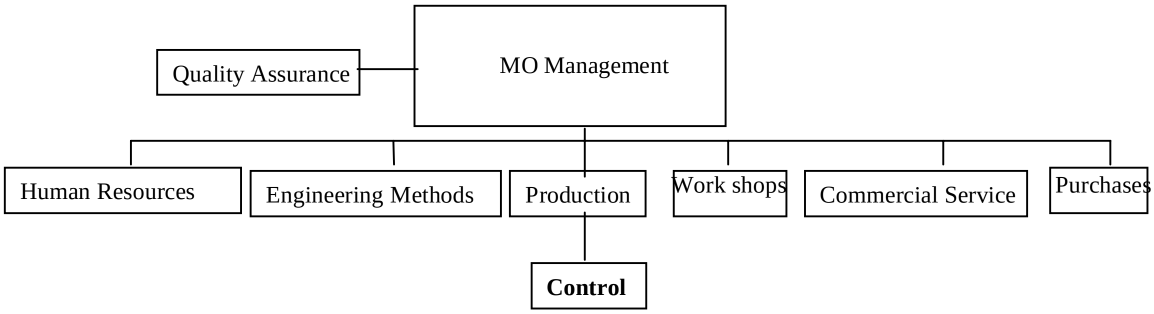
Simplified flow-chart of an MO (control and production separate)

Figure 4: example of the positioning of control externally to the production service.

In this case, the externalisation of control, in relation to production, enables the controllers to be « independent » of any demands and constraints of the production service.

- The present trend is the integration of the controllers (then called inspectors) into the production service, as represented in the diagram below. However, from a functional point of view, the control procedures applied are issued from the MO own quality plan, and conforms to the new regulations.

[2] Depending on the MO, the service that manages the maintenance yard may be called production, maintenance …



Simplified flow chart of an MO (controlled by production)

Figure 5: example of the attachment of control to the production service.

In these situations, the interviews with the controllers have raised the question of the autonomy of control in relation to the production service:

- For production, one of the high-level objectives is to deliver the aircraft on time,
- For control, the aim is to guarantee that the interventions as well as their results validate the airworthiness of the aircraft.

These two objectives can be contradictory. The trend of progressive integration of control into the production service could induce a risk of favouring the objective of cost management to the detriment of the safety objective.

➢ ***In chapter 4, we present the notion of self-checking (in other words, the first level of intervention control exercised by the front-line operators themselves) and we examine more precisely the conditions of implementing this process in the case of interventions on new generation systems.***

3.4. THE TRACEABILITY

Traceability, as we have already seen, forms a part of the process of intervention control. This function is supported by the work cards and therefore depends directly on the conditions of task accomplishment (Ref. annexe 5).

The first purpose of traceability is to be able to respond to questions such as « who did what? » and « what has actually been done? », in order to finalise the visit file and deliver the ARA (Ref. annexe 4).

In cases where tasks are not signed or where the signatures are not confirmed, the information is returned to the control process.

The demands for signatures can be different according to the tasks involved, the type of work to be performed, or the critical level of the system on which the intervention is being performed:

- In the simplest case, only the signature of the worker performing the intervention is required (T_a in the table).

- For tasks requiring the involvement of two workers, the co-signature of the card or a part of the card can be required (T_b).
- The permit for certain tasks can be issued only by the control service (T_c).
- Finally, for other tasks, workers and controllers are jointly responsible for the tasks to be performed r (T_d).

Tasks	worker	worker	controller
T_a	yes	no	no
T_b	yes	yes	no
T_c	no	no	yes
T_d	yes	yes	yes

Figure 6: table of demands of traceability according to type of task .

Evolutions within the phase of traceability were not found to be homogeneous for all the MO visited. These evolutions concern the movement from a paper-pen method of traceability to one of electronic traceability directly connected to the work card: each worker « opens » and « closes » his card as a means to record a bar code that identifies him as the executor of a given task.

Different systems are put in place and one can note the variability of their current use.

A prime use of this new method of traceability resides in the management of real time and in the availability of human and technical resources. A second indirect use was established from the process of improving time calculation and therefore the costs of intervention for each type of task. Such results are used for establishing quotations for clients.

- ***A part of the analyses presented in chapter 4 deals with the difficulties caused as much by the format as by the content of « traditional » work cards. As with the control, the analyses presented concern the traceability of the interventions on the New Technology systems.***

4. THE ANALYSES: THE FRONT-LINE OPERATOR AS CONTROL AGENT

The global evolutions of the organisation of the maintenance process, presented in the previous chapter, are analysed here from the **regulating processes and the decision-making** which are necessary for adapting the prescribed task to the real intervention conditions in the work shop. This analysis reveals **the increase and concentration of the regulating processes on the front-line operator.**

Indeed, in affecting the internal dynamic of the maintenance process (its organisation), the external transformations (New Technologies, economic pressures and regulatory evolutions), transform the content and the conditions of intervention operation for the front-line operators. This hypothesis is illustrated by the following figure:

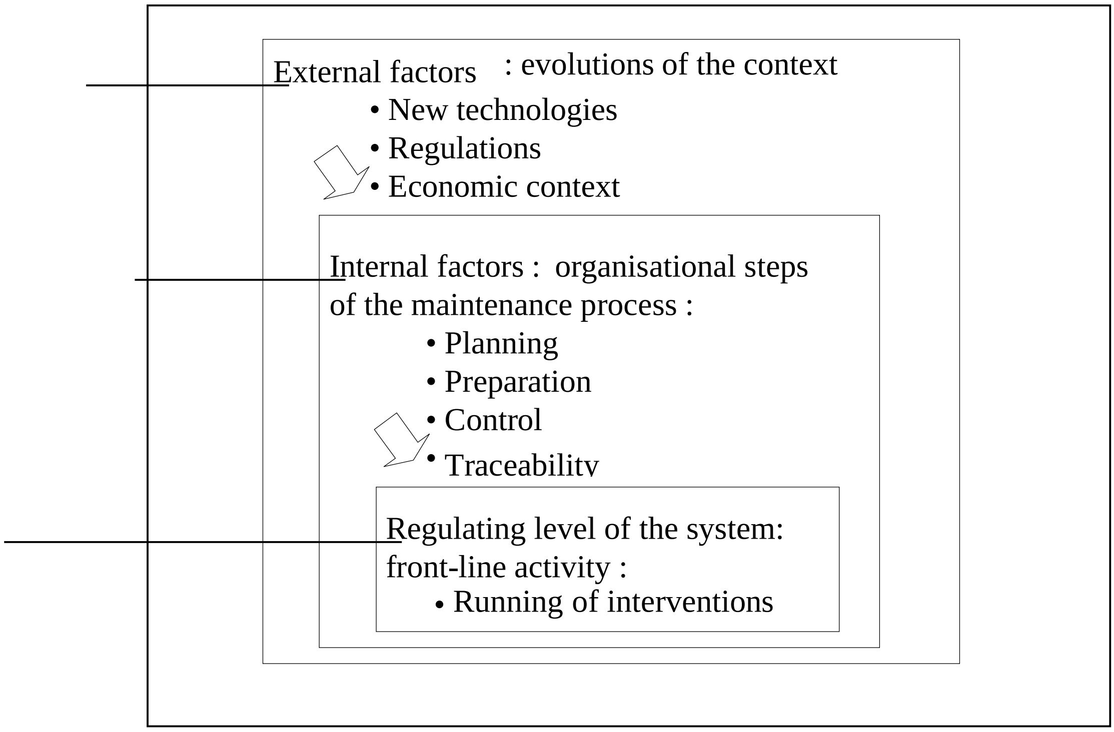


Figure 7: the combined influence of the external and internal evolutions on the operation of maintenance interventions.

However, the workplace mechanisms of optimisation that can allow coping with industrial constraints are fragile[3]. These mechanisms rely on the competencies of the front-line operators and just until recently, on the possibility of resorting to a close technical expertise in order to validate the current choices, or to activate a superior level of responsibility.

We note that the technical support permits by the personnel of close supervision is still possible as long as those supervisors come from the workshops. But such supervision is limited, taking account of the loads and administrative demands falling under their responsibility.

Besides the risk of « saturation » of the proximity supervisor in the current phase of transition, one can posit the existence of certain risks, based on the observation that regulating methods are focussed on the front-line operators.

These risks should be considered at different levels, according to the type of difficulties that they may allow to occur. The following paragraphs present and discuss the different types of difficulties observed:

- those linked to the use and management of traditional work cards,

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[3] Similar results are observed in other domains. Concerning nuclear maintenance processes, we can cite, for example, the article from M. Bourrier which appeared in the May-June 1988 edition of the journal entitled "Performances Humaines et Techniques : *Le pouvoir sur les règles : la gestion des procédures de maintenance dans l'industrie nucléaire*".

- those linked to the use of the manufacturers documentation,
- those more specifically related to the maintenance of equipment integrating New Technologies.

4.1. DIFFICULTIES RELATED TO THE USE AND MANAGEMENT OF WORK CARDS

Within the frame of his daily activity, the front-line operator is obliged to adapt the mode and the conditions of task operation to the state of the system (aircraft context) and the environment (availability of related systems, access to controls etc).

This regulating activity of front-line operators is fundamental and in most cases transparent for the supervision management. Such activity is based on an evaluation of the relevance of actions described in the work card, and based on operational methods recommended by the documentation. For example, the strict application of AMM procedures can lead to a loss of time, linked to the implementation of prescribed conditions of intervention or the operation of actions useless in the context of programmed intervention.

Due to this time lag, the front-line operator is subjected to the following demands:

1. The reorganisation of the tasks in real time based on available resources and the representation of the current aircraft situation.

   In these situations, several discrepancies appear between the traceability of work cards and the real situation, whether this relates to the chronology of events or the identification of persons.

2. The management of implicit tasks due to the considerable number of AMM sub-tasks contained within a task.

   The operator is obliged to evaluate the necessity of actually following the sequences of actions prescribed in the documentation. On the one hand, he must take account of time and the resources allocated by the planning of the principal task operation. On the other hand, he must take account of his own individual knowledge of the task, and therefore must evaluate the necessity to refer back to a detailed work card.

   From the point of view of organisation of traceability provided by the work cards, the cross-reference system of working from task to task poses the question of knowing whether the signature of a task implies its completion and/or the respecting of operational methods included in the process. In the example given in annexe 3, are the MO and the operators committed to all of the 17 tasks involved?

3. The put on « hold » of interrupted work cards due to the inadequacy of the aircraft context.

   This interruption leads to the use of a « stand-by » stock of work cards, during the period of waiting for official work cards to be developed in the workshops. The information from such temporary cards is not systematically transferred to the planning service.

   This process increases the discrepancy in terms of knowledge about the aircraft status between the planning, which continues to run its program, and the workshop, which is confronted with the real state of the aircraft. The question here is to know whether the operator is in a position to re-transcribe on the work card (or to re-transfer) all the particular situations encountered and therefore the interventions actually performed.

4. The obtaining of signatures corresponding to the context of real work.

Here, we report two examples of difficulties encountered:

- The first example is taken from the monitoring of a worker and a trainee in the operation of a task involving steering tests. To perform this task, the procedure requires that the first operator be in the cockpit. He is in charge of manipulating the controls. Under the wings, the second operator verifies visually the response of the flaps to the controls of the first operator. This task is to be performed twice for the right valves and twice for the left valves. To do so, the AMM requires that this work be performed by two workers of the same competence, with rotation of roles (steering commands / visual verification) between the two operators. This is identified on the work card by the tables of signatures (4 signatures are requested). However, what really occurred during this operation is that the worker manipulated the commands for the right and left valves. The trainee, by himself, managed the visual verification. Here, the worker exercised two levels of adjustment, one in terms of non-conformity of competencies (a trainee / a worker), and the other in terms of non-reiteration in the rotation between the two operators. The worker knew that the intervention did not conform to the AMM. He justified his choice, on the one hand, in considering that his trainee was capable to verify that the valves move. To the question « how are you going to sign this card ? » his response was the following : «I look for a colleague having the competencies required by the card. He knows me, he will sign».
- The second example illustrates the recovery by the control of a card signed in a non-conforming manner. The planning presents the controller with a work card, returned 48 hours earlier but signed incorrectly. The intervention involves the visual verification of the absence of signs of wear and of non-contact in the electrical circuits located under the floor of the cockpit. The card comprises several tasks, some of which are under the responsibility of the worker (case T_a in table of signatures, chapter 3.4), whilst others must be performed and signed co-jointly worker / controller (case T_d). The intervention is performed, the worker's signature is the administrative proof, but the intervention is not signed by the control. The controller that recovers the card searches for the worker. He supposes that the worker simply did not notice that a part of the card was to be carried out jointly. The worker is no longer on the maintenance yard. The intervention concerns an interim, and the controller is not provided with any information about him, notably in terms of competencies. The controller knows that a part of the verifications can be performed from the electrical bay[4]. He takes the responsibility of uniquely verifying the part accessible by the bay. He signs the work card based on this visual verification performed.

[4] To conform to the AMM, one must disassemble the floor in order to visually access the concerned parts. The whole assembly/disassembly of the cockpit floor process lasts seven hours. This disassembly has very important consequences, such as blocking access to the cockpit, preventing all cockpit activities to occur.

The regulatory evolution of the MO control process transfers the structures and the methods, previously orientated towards the technical management of the process, towards its administrative management, through notably, the implementation of administrative indicators of performance.

From the front-line operator's point of view, the control process remains above all, based on self-checking: the worker verifies that the work that he has performed fulfils the high-level objective, which is the airworthiness of the aircraft. This intra-individual process is independent of the administrative process and relies instead on the competencies and professionalism of the front-line operators.

- ***To summarise, the discrepancies revealed by the difficulties of using and managing work cards leads one to question the efficiency of the different administrative criteria that mark the phases of the maintenance process, from the planning phase to the measure of intervention performance.***

4.2. DIFFICULTIES RELATED TO THE USE OF MANUFACTURER DOCUMENTATION

The present situation reveals the difficulties linked to the discrepancy between, on the one hand, the content and the structuring of the manufacturer documentation, and on the other hand, the operational needs of the front-line maintenance operator.

The following paragraphs describe the types of difficulty observed regarding the use of the manufacturer documentation:

1. The difficulties of taking into account the aircraft context.

   The manufacturer's documentation is organised by zone and by system. The description of an intervention is based on the characteristics of the system (elements that make up the system, functions' principles …), and the system zones, in terms of a given aircraft context (aircraft on wheels, electrical and hydraulic supplies in service…).

   The reality of the aeroplane's state during programmed visits is different: the aircraft is partly dismantled, raised on a jack, with certain systems disconnected, without energy or power…

   The execution of an intervention requires, most frequently, an adaptation of the instructions described in the AMM procedure, in terms of modifications, the addition or removal of certain sequences of action (ref. example of work card in annexe 3).

2. The difficulties of access to information

   The principal quality of the AMM documentation is its exhaustive nature. It describes each type of intervention on all aircraft systems. Its organisation is based on all cross-references between tasks, allowing to interlink some into others (ref. example of work cards in annexe 3).

   This kind of documentation organisation, although it allows a design office to have access to all technical information, is not adapted to the practical needs of an operator in a workshop.

   Practically, an operator benefits from the whole document management system in accessing an AMM piece of information. However, realistically, he confronts the issue of volume, as portrayed in the following cases: 1) a work card can refer to several hundred cases of AMM tasks (845 for an example given by an OM), 2) a AMM task cited within another task can represent nearly a hundred pages of instructions (75 pages in an case observed on site).

   Such an abundance of data and documentation renders it difficult for the operator to exercise a systematic approach of research and consultation. A consequence of this is that it influences the operator's decision, according to his competencies, to go or not, in search of complementary information during the execution of an intervention. Nevertheless, the process of navigation validation is based on, among other things, the criterion of a guarantee of respect of all prescribed procedures.

3. The difficulties of integration in the organisation of work

   The work cards of the major aircraft manufacturers are written in technical English, which poses problems of comprehension in the case of actions that are non-routine.

   The tasks described in the AMM are structured within a technical logic. They describe the path of action to follow in accordance with a technical logic associated to a precise aircraft context.

   The execution of an intervention, if it relies on this technical logic, must also take into account the organisation of work. The front page specific to the MO in annexe 1 provides an example of this 'taking into account' (specialities, tools, delay in execution, workforce...).

   However, the reduction of preparation costs, that comes with resorting to the crude tasks described in the AMM document, creates divergences between the resources identified at the time of launching the card and the prescribed tasks.

   The distributed AMM tasks, such as those given to the operators, integrate a series of multiple actions that may, for the planning authority, be unidentifiable, given that the planning authority is focussed on the global objective of the task.

4. The difficulties of updating the documentation

   The quality of the technical information provided by the manufacturer is not absolute. Beyond the structuring of this documentation (referred to above), lies the problem of the format of this information, in terms of its usability in maintenance situations by the operators. Notably, the MO are confronted by the recurring problem of the preciseness of the information. Two examples illustrate the dysfunction and the regulating actions that can be associated to assisting the completion of the task :

- The intervention concerns a dysfunction of the electrical circuit (annexe 4). The window lights in the cabin are out of service. The worker searches for the electrical diagrams in the microfilm documentation. The part of the diagram that is of interest to the worker is unreadable. The operator prints the electrical diagram for another aircraft considering that the circuit is identical. This is not the case. He reconciles the two diagrams in order to continue with his intervention.
- The intervention concerns the modification of the TCAS system (annexe 2). The team is delayed twice due to errors in the manufacturer’s diagram and the test procedure. The economic impact is significant (4 hours for 3 people + the risk of not delivering the aircraft on time).
- Concerning more particularly the interconnections of systems, the example cited in annexe 2 highlights the numerous imprecision regarding the assignment to input-output definition, on the cabling plans, etc…

It is common to find errors in the documentary supports with which the workers work. This raises the question of the level of confidence the front-line operators have in their work supports.

➢ ***To summarise, we note the passage from the use of a « made to measure» type of documentation to a « ready-to-wear» type of documentation. For the front-line operator, this evolution induces an activity of adjustment between, on the one hand, the design logic, embedded in the AMM documentation (which serves to support the preparation of work cards), and on the other hand, the operational logic that constitutes the activity actually implemented.***

4.3. DIFFICULTIES RELATED TO THE INTRODUCTION OF NEW TECHNOLOGIES

The complexity of integrated piloting functions (GPWS, TCAS…) requires the use of very controlled test environments. Furthermore, the integration of such functions, in terms of the multitude of interconnections between the systems, is maintained by implementing complex test configurations. That is to say, by integrating several systems in order to fully evaluate each function.

The MO do not themselves intervene in the maintenance of the systems but are themselves involved, more and more, in the replacement of these systems. Such systems are becoming so complex and impenetrable that the electronic cases provide very little visibility with respect to their internal functioning. Interventions on these systems are only accessible through the manufacturer’s test procedures, where again, the front-line operators have very little means of visibility at their disposal.

We have identified two categories of the impact of new technologies :

1. Test systems are more and more impenetrable.

   After re-assembly, the procedures include the use of built-in tests programmed in the system. The difficulties encountered in performing the intervention cited in annexe 2, demonstrates that access to such systems is critical for having a comprehensive understanding of the conditions and modes of functioning of these test systems.

   The lack of comprehension of test steps and of tested parameters prevents operators from going beyond the «OK test » return code displayed by the system itself. The lack of comprehension of particular parameters (in terms of test environment, or state of sub-systems that are adjacent to, but nevertheless involved in the running of the test); such parameters playing an important role in the validation of a system, prevent the operators from adapting to the particular situations.

   The multiplication of test situations makes it difficult, even impossible, to fulfil the demands of the contradictory situations. This doubt in test situations is reinforced by the impossibility of setting parameters for these tests to adapt them to the context of a programmed visit: the built-in test can be valid even when the system is partly disconnected. The multiplication of this test logic, issued from different manufacturers, reinforces this doubt in the validity of these pre-formatted tests.

2. The systems tested are more and more complex and interwoven.

   Take for example an AMM task of decontamination of the calculator rack. This « routine » task highlights the particular conditions of intervention that the operators must face, on the integrated systems. In such conditions, this task is relatively new in terms of the operational means that the operator must exercise.

   The task involves the decontamination of the avionics compartments and the cockpit (AMM task 12-21-13-100-001).
   This task regroups the disassembly/cleaning/re-assembly/tests of different calculators and equipment located in the avionics bay and the cockpit.

   This task involves 845 Maintenance Practice tasks and it concerns 13 systems regrouped under the following 13 ATAs :

Air conditioning	*Flight controls*	*Navigation*
Auto flight	*Fuel*	*Pneumatic*
Communication	*Indicating/recording system*	*Engine fuel and control*
Electrical power	*Landing gear*	*Engine indicating*
Fire protection		

Most of these systems are interconnected and because of this, there are 39 test configurations to be realised, which leads to a total of 232 tests to be performed. In such conditions, the mounting and test sequences require that a chronology be followed very precisely.

Within this situation, the letters from the MO to the aircraft manufacturers are a source of numerous technical and organisational difficulties concerning the running of the task. Such difficulties can be organised around two main concepts:

- Redundancy .

Because of the multitude of tasks contained within a AMM task, numerous actions are duplicated many times; as for example, with the opening and closing of zones, the configuring of systems, etc…This considerable cross-over of actions leads to, in all cases, problems of effective traceability, and very often, difficulties to evaluate and prepare for the real work load of a task.

- Interference.

This concerns the incoherence between the required actions and/or the current configurations of sub-systems. Conflict between actions is caused by the preparation teams' difficulties in describing rigorously the chronology of actions. An example of such chronology may be: to close an access zone in order to conclude a task on an ATA, and to reopen this access zone to fulfil the needs of another task. Another cause of conflict is the configuration between sub-systems. For example, in an AMM task, the position of circuit breakers, which assure the closing of electrical circuits, is a real headache for the operators. They must alternate between opening the circuits, to assure their own safety and that of the systems being manipulated, and closing the circuits to run the intermediary tests of functioning.

From the front-line operators point of view, these systems represent the « black boxes » for which they do not control, nor visualise the principles of internal functioning. They are therefore blind to the validity of test responses and so, have no final guarantee of the nominal functioning of the system.

- ***To summarise, the fundamental question concerning the validity of pre-formatted tests on the new generation equipment, is linked to the conditions of evaluation airworthiness subsequent to an action of maintenance. By a process of self-checking (« make sure that »), the front-line operator participates in the engagement of the MO in the restoration of this status. However, the content and quality of the test evaluating the airworthiness is today the responsibility of the equipment supplier. The MO is in the position of test user and verifier of the conformity of the response. The front-line operator loses any possibility of validating the internal functioning of the system and of intervening in the means of verification.***

5. RECOMMENDATIONS

Here, we will examine three levels of recommendations, relating to the:

- passage from a documentation relating to the design to one of operational use,
- format of work cards organising front-line operator activity,
- preparation of the interventions taking into account the transverse nature of the systems.

5.1. FROM A DOCUMENTATION OF DESIGN TO ONE OF OPERATIONAL USE:

The documentary support (essentially in the form of work cards) is an important support of maintenance activity.

Several discrepancies are revealed between the initial functions of this documentation and the resulting conditions of its implementation in the workshops:

- The presentation format: the field analysis demonstrated that the work cards fulfil multiple functions. They serve not only to support the action occurring, but also to follow the planning and to support the traceability (who did what) and legal filing. The current « online » format proves to be ill-adapted to the timing organisation of work, to the transfer between teams, and to the interruptions of interventions (cleaning, implementation of technical means…). This format has an entirely descriptive function and is not thought of as a work support by the users: the maintenance operators.
- The organisation of the information: because of the complexity and the interconnection of technical equipment, the documentation is based on extracts copied exactly from equipment documentation: the ATA (Aircraft Transport Association) and a system of cross-references between inter-system tasks. The number of cross-references associated with an elementary task renders it impossible to systematically consult all the relevant tasks involved. The front-line operator is therefore led, according to his own estimated mastery of a task, to decide if he needs, or not, to resort to the AMM documentation.
- The format of information: the generalisation of English poses problems of comprehension for certain operations in specific tasks. In most situations of such comprehension problems, the controllers serve as a last resort.

➢ ***In this context, the sustained ability to regulate the activity during the intervention requires, on the one hand, a better organisation of the sharing of technical information between the manufacturers and the OM. On the other hand, before the preparation of interventions, a distribution of responsibilities between the manufacturer and the MO is required, in such a way that the latter is able to exploit a formal work-card system that integrates the temporal cut-out of interventions (specific tasks are often interrupted by other tasks or considerations and then resumed) and the real contexts in which the interventions are performed.***

5.2. THE FORMAT OF WORK CARDS ORGANISING FRONT-LINE OPERATOR ACTIVITY

Maintenance activity is characterised by a large flow of documentation in the form of work cards. Firstly, work cards serve as links between the planning phase and the workshops. Subsequently they serve as a transfer of information between the different actors intervening in the aeroplane: the succession of teams, the different specialities, the operators and the supervision, the operators and the control.

The difficulties observed in the field concerning the use of these cards are largely due to the discordance between the multiple functions of these cards and their paper format. The work cards have three functions, each affecting different aspects of the work situation:

1. The planning and the follow-up of performance of maintenance actions:

   The work card serves as a triggering signal of an activity when it leaves the planning phase for the workshop. Once in the workshop, it travels between the different operators involved in the running and follow-up of interventions. This support is negatively affected by task interruptions due to cleaning activities (never described in the work cards), supplies problems or rotation of operator teams. The work cards remain on the work desks, attached to the elements undergoing maintenance …

2. The traceability of actions performed:

   The work card (its first page) comprises the legal support enabling one to certify the running of the maintenance programme and the identification of the operators that performed the interventions (for verifying the qualification and the necessary accreditation). This function depends on the guarantee that work cards are retrieved with all necessary information, notably concerning the people involved.

3. The presentation of an operating method and the related technical information:

   The work card serves as a work support for the operators in presenting a description of actions to be undertaken and the technical information concerning the relevant systems. This function necessitates that the operator carries his card on him on the site of interventions, and that he always keeps the card close to him. Moreover, this information is presented in the form of texts that are often quite long, which can pose problems of legibility (annexe 6 presents a work card issued by the AMM along with the re-transcription carried out by operators in the workshop to facilitate its use and to improve the quality).

These three axes of functionality are very often in conflict with each other due to their sole paper support.

While one must consider the conditions for using this information support, throughout the lifecycle of a work card, one can extract the information pertaining to different axes of functionality that are less relevant to a given task.

This « extracting » activity has two major advantages:

⇒ Each work-card format is adapted to its function.

⇒ To limit the shifting of operating modes so that operators are able to keep them close to the zones of maintenance.

By way of an example, the following format enables one to fulfil this objective:

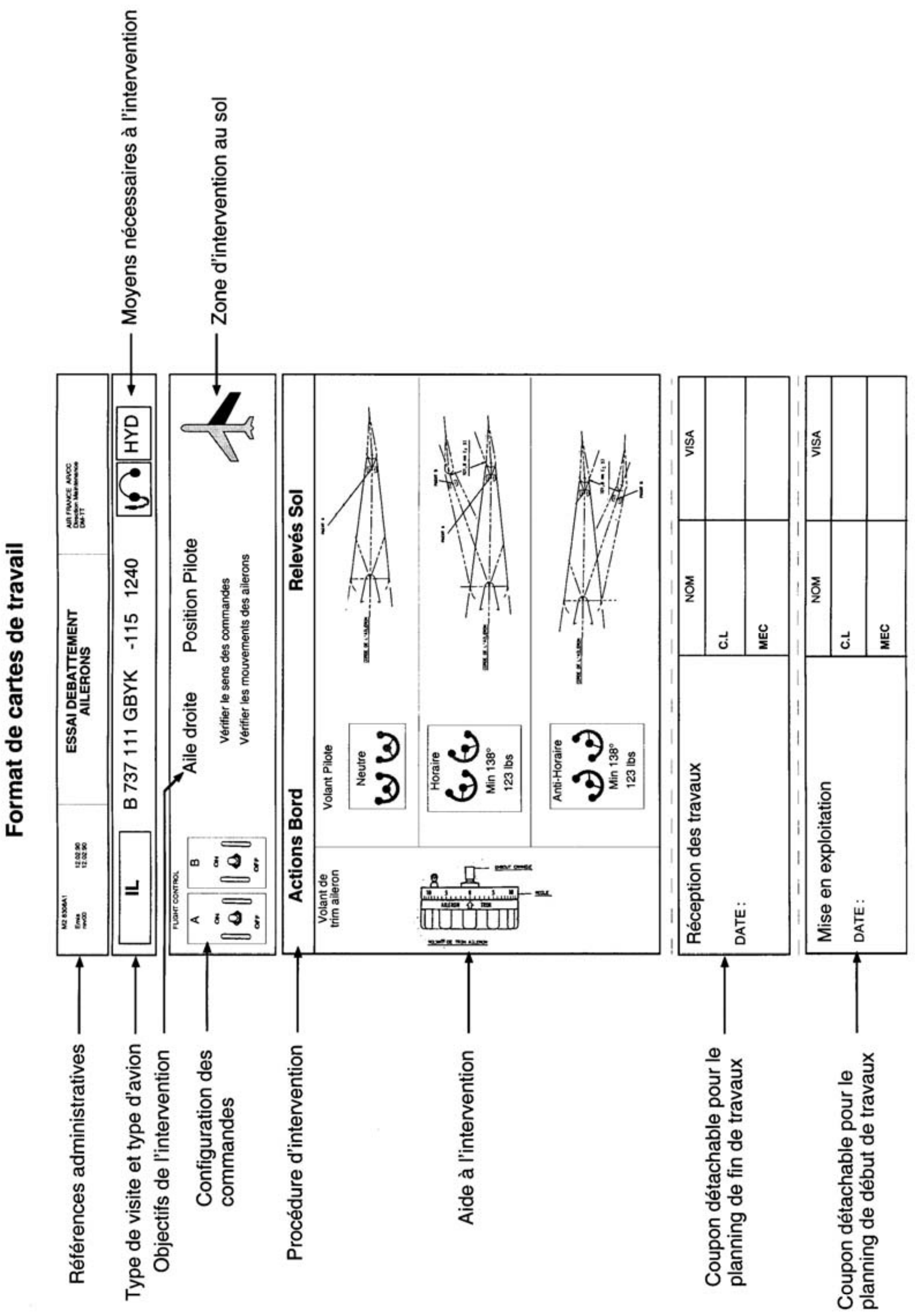

Figure 8: proposal of format for an operational work card.

5.3. THE PREPARATION OF INTERVENTIONS AND THE CONSIDERATION OF THE TRANSVERSE NATURE OF SYSTEMS

The structure of technical documentation, based on the design of a system, is naturally isomorphic to the system structure and to the eventual dissection into sub-systems. This organisation of information aims to support the exhaustive nature of technical content.

The structure of documentation oriented towards the action must take into account the interconnection of systems within a single unit: the structuring elements are those that are transverse to each sub-system comprising the overall system. As such, the example of the decontamination of the rack, which supports a part of 13 different systems, is indicative of the problems encountered during the interventions on the interconnected systems. Such problems appear to be symptomatic of the divergence existing between the representation of a system from the designers' point of view and that characterising the operational maintenance point of view:

- The structure of the first representation is based on the functions of the aircraft and on each chain of treatment of information (the ATAs). The functional description, the interactions, and the classes of interventions planned and described for each function are structured within the internal system. From this perspective, the common rack is considered as resulting from the sum of systems that it supports. Interventions on the rack are organised by summing up the operating modes issued from each sub-unit (hence the issues of redundancy and interference).
- The second representation considers the rack as an entirely separate equipment, requiring specific information and operating modes that correspond to the complexity of the interventions on all the supported and interconnected calculators.

The convergence of these two representations could be considered at several levels with, in each case, heavy and specific constraints:

1. For the aircraft manufacturer providing the documentation of operational use:

   To put in place, from this level on, « transverse » information corresponding to operational modes of maintenance (example: to take into account the fact that the decontamination of an equipment does not depend on the logic of each of the systems that it supports), would require, on the part of the constructor, a complete change of logic and a strong increase of the number of tasks to be integrated into the documentation.

2. For the MO using this documentation to prepare interventions:

   A solution in the past was to adapt the manufacturer information to the particular maintenance programmes (annexe 6). Several aspects militate against this solution:

   - The reduction of costs and the curtailing of functional lines (maintenance preparation and design office) and management lines (technical proximity supervisor).
   - The growing complexity of interactions between the systems and the lack of means to adapt (even rectify) the documentation (trial and error tests, or return to the manufacturer due to lack of information).

Within the current framework, the consequences for the front-line operator are, on the one hand, the lowering of the reliability of information contained in the technical documentation and, on the other hand, the obligation to « test » such information in situ.

6. CONCLUSIONS

These observations of aeronautical maintenance activities in the OM were carried out within the restricted context of programmed maintenance: checks A to C of medium-haul and long-haul aircraft. Maintenance on the ramp, in workshop or equipment maintenance, was not taken into account.

This work was achieved thanks to the participation of five French organisations. However, for diverse reasons, we were not able to depend on the required access to on-site observations and interviews with front-line operators.

Finally, regarding the background history for the project, we were able to benefit from certain interval of time, between phases, necessary to anticipate the evolutions that emerged for the OM, without, however, being permitted to witness the final outcomes of these evolutions.

Taking into consideration the above remarks and the results obtained, it now seems useful to carry out the following two axes of complementary investigation:

1. To broaden the field of validity of these results in considering:
    - Other situations of aeronautical maintenance. Indeed, one may think that the organisation and the performance of interventions on the ramp, for example, may give rise to another logic, as much regarding the point of view of preparing interventions, as regarding the use of documentation or the types of systems maintained.
    - The cultural origin of the maintenance organisations. Indeed, this work was only carried out with the participation of organisations stemming from a culture of former airlines' OM. One may think that the professionals' system of reference observed notably during the self-control process, could be of a lesser magnitude for the organisations stemming from a strictly industrial culture. Notably, what bears reflection here are the demands that recover the notion of airworthiness.
2. To validate the durability of observed regulating modes, taking into consideration that:
    - Within the global context of the evolution of equipment to be maintained, one observes the necessity of enforcing a specialisation requirement for the workers intervening on these systems. The EIR[5] teams are trained as the intervention needs arise. In parallel, the organisation puts in place and utilises the polyvalence of the workers on the maintenance yards to respond to the evolutions of the regulations (JAR 66) and to the logic economy.
    - This present work highlights the importance of technical competencies as the essential base supporting the regulating modes. On the one hand, one may think that the equilibrium observed today may be endangered or, in any case, modified by the oncoming loss of current competencies (as much for the front-line operators as

[5] EIR : Electronic, Cockpit Instruments and Radio

for the operators assuring today the functions of proximity supervision). On the other hand, it may be modified by the massive introduction of competencies acquired and validated on new modes and implemented according to the new demands. A longitudinal study in the mid-term, of the impacts of the application of the new regulations arrangement (essentially the JAR 66 and 145) would enable one to readjust the current results.

7. LIST OF DIAGRAMS

